DISTRICT OF COLUMBIA
WATER AND SEWER AUTHORITY

DC CLEAN RIVERS PROJECT

TECHNICAL MEMORANDUM NO. 6: GREEN INFRASTRUCTURE TECHNOLOGIES

May 4, 2012

Prepared for:

dc water is life

Prepared by:

dc clean RIVERS PROJECT
RESTORING OUR RIVERS
PROTECTING OUR DISTRICT

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1 Introduction

The purpose of this report is to provide a concise summary of select Green Infrastructure (GI) Technologies that are deemed to be the most relevant for use in the District of Columbia as part of DC Water's proposed Green Infrastructure Program. This primarily relates to the suitability of these practices for use in an urban environment to provide volume reductions to aid in reducing the occurrence of Combined Sewer Overflow (CSO) events.

There are a wide range of potential GI technologies currently in use throughout the country, and many of these include numerous design variations. There are likewise hundreds, if not thousands, of documents and design manuals available that describe these GI technologies in detail. The intent of this report, therefore, was to select and summarize important aspects of the relevant practices, rather than to provide a detailed design document. Review of this report will enable DC Water staff to quickly discern the practices that may be of most use for a particular application. Detailed design specifications developed by others can then be consulted to implement the selected technology.

With the above considerations in mind, review of available GI technologies has resulted in the selection of the following for inclusion in this report:

1) **Bioretention**
2) **Pervious Pavements**
3) **Soil System Detention**
4) **Vegetated Swales**
5) **Green Roofs**
6) **Rainwater Harvesting**
7) **Blue Roofs**
8) **Filter Systems**

The report is organized with a separate chapter for each technology. Within each chapter are sections that provide an overview of some important aspects of the technology that were developed to assist DC Water staff in selecting the desired practice. The sections that are included are described below, along with a brief summary of the type of information that is provided:

1) **Description** – Provides an overview of the technology.

2) **Feasibility Considerations** – This section describes some basic parameters relating to the proposed site that should be considered when deciding whether or not the technology is appropriate for the intended application.

3) **Basic Design Elements** – Though not intended to provide detailed design specifications, this section does include more general design parameters and some typical ranges for these parameters.
4) **Important Construction Considerations** – There are some basic construction guidelines that can impact the success of the technology before it is even put into

practice. This section outlines steps that should be taken to prevent premature failure and/or to ensure the practice performs as intended.

5) **Operation and Maintenance** – This section provides guidance concerning some recommended measures to keep the technology operating efficiently and to prevent premature failure.

6) **Performance Criteria** – Ranges of some typical performance for volume reduction and pollutant removal (for total phosphorus and total nitrogen) are provided. There are numerous design options that can determine the effectiveness of the technologies. This section provides overall ranges to aid in gauging the overall potential for the practice.

7) **Cost** – Various sources of cost information were reviewed in order to provide a range of typical values for each technology.

8) **Applicability to DC Water** – This section provides a brief analysis of how the technology can benefit DC water, specifically in terms of feasibility in an urban environment, as well as the potential for providing effective volume reductions.

9) **Detailed Design References** – As discussed above, the intent of this document was to provide an overview of the technologies, not detailed design information. This type of guidance is available through various sources, several of which are provided for reference.

10) **Example Applications** – This section provides a few schematics and photos as examples of applications in use in similar situations.

2 Bioretention

2.1 Description

Bioretention is a practice whereby runoff is collected in shallow depressions and is allowed to infiltrate through an engineered soil media consisting of sand, soil, and organic matter. The cell is planted with suitable vegetation capable of withstanding the hydrologic extremes (periods of inundation followed by periods of dryness, which are a result of the high sand content). The surface of the facility is covered by a layer of mulch and, depending on the permeability of the in-situ soils, often includes an underdrain that collects and discharges water to a suitable outlet. Water quality and quantity benefits are achieved through physical filtering, biological, and chemical mechanisms, as well as through retention, absorption and infiltration.

Bioretention facilities can be known by many names, including bioretention basins, bioretention filters, or rain gardens, among others. These names are sometimes based on the size (with rain gardens typically referring to smaller scale facilities) and/or functionality (without or without underdrains), but all act in the same manner. A primary benefit of bioretention facilities is that they can be tailored to fit the specific situation, even in tight urban settings and/or along roadways. They also provide an aesthetically pleasing alternative for the treatment of stormwater that can be integrated into the landscape.

Figure 2-1. Curb-extension bioretention facility (Source: UACDC LID Design Manual for Urban Areas)

2.2 Feasibility Considerations

As with any LID practice, there are constraints to be considered with the use of bioretention facilities. Some of the more important considerations include:

2.2.1 Contributing Drainage Area

Publications recommend no more than 2 acres (ac.) drain to the facility with no more than 50% impervious cover for typical bioretention facilities. However, in urban situations, drainage areas tend to be much smaller (2,500 s.f. to 1 ac.) and contain up to 100% impervious areas. Larger drainage areas can be accommodated (up to a maximum of 5 ac.) if other limitations are taken into account in the design. Flow splitters can be utilized to divert larger storms around the facility to accommodate larger contributing drainage areas and/or to isolate the desired treatment volume – a typical situation in urban settings.

2.2.2 Available Space

Bioretention facilities can be tailored to fit the available space – one of the big advantages of this practice. The overall footprint will be determined in conjunction with other design parameters, such as design depth, soil infiltration rate, and desired level of treatment. However, 3-6% of the contributing drainage area is a rule of thumb. Much smaller ratios are achievable with high infiltration rate media[1], but this sacrifices the volume reduction benefits of bioretention facilities.

Figure 2-2. Small bioretention facility retrofitted in a busy urban setting. (Source: Nevue Ngan Associates)

[1] *Higher sand content or proprietary media, such as Filterra.*

2.2.3 Topography

Generally, bioretention facilities function best on sites where the slope is in the 1-5% range. They can, however, also be used in steeper situations (10-20%) through the use of terracing practices.

2.2.4 Available Hydraulic Head

For systems draining to a stormwater conveyance through an underdrain, there must be a sufficient difference in elevation to make sure the underdrain flows freely and does not inhibit the flow through the filter bed media.

2.2.5 In-Situ Soils

The lack of permeability of the soils present on the site does not inhibit the use of bioretention practices. This is a particularly important point in urban settings where compacted fill is commonplace. Underdrains are supplied when soil infiltration rates are unacceptably low (typically less than 0.50 in/hr), or can be included and capped off to provide a back-up should in-situ infiltration rates worsen over time. Another option is to employ a raised underdrain outlet that provides for some storage to allow the opportunity for infiltration (i.e. Internal Water Storage, or IWS), but does not rely on it.

Figure 2-3. Bioretention planter box in Washington, D.C. (Source: ceNEWS)

2.2.6 Water Table

It's important to make certain that the seasonably high groundwater elevation is a minimum of 2 ft below the bottom of the facility. This will inhibit the potential for groundwater contamination, as well as the potential for high groundwater levels to inhibit the proper draining of the facility.

2.2.7 Pollutant Hotspots

Use of bioretention to treat runoff from land uses with the potential for high pollutant levels should be avoided, or pretreatment provided that is tailored to the type of pollutant expected.

2.2.8 Utility Conflicts

As with other practices, conflicts with utilities (both under and above ground) should be avoided.

2.2.9 Location

Bioretention facilities should not be located within 100-yr floodplains or in areas that receive a baseflow. Care should also be taken to keep these practices away from buildings and water supply wells – distances of 10 and 100 ft are cited, respectively, but depend on the particular design parameters (size of the facility, type of soils, etc.). In urban settings, they can be placed immediately adjacent to buildings if the buildings are waterproofed and/or an impermeable liner is used.

2.3 Basic Design Elements

Bioretention facilities can be designed to fit the available site and to meet the specific water quality/quantity requirements. Thus, there are numerous design variations. However, there are some basic elements that each typically has in common, as summarized in the following table.

Table 2-1. Bioretention Typical Design Elements

Design Element	Typical Values
Drainage Area	1-3 ac
Ponding Depth	6-12 in. (lower reduces maintenance costs and allows more diverse vegetation)
Soil Matrix Composition	85-88% sand, 8-12% fines, 3-5% organic. 2-6 in/hr initial infiltration rate.
Soil Matrix Depth	2-6 ft. Deeper for facilities with trees; 3 ft typical
In-Situ Infiltration Rate	> than 0.5 in/hr
Gravel Bed	As necessary for underdrain or for storage, 12-18 in
Underdrain	6 in schedule 40 PVC with 3/8 in perforations
Geotextile Fabric	Non-woven, along sides and above underdrain only with gap-graded sand/gravel filter above the gravel bed
Mulch Top Layer	3-in., double shredded hardwood
Side Slopes	< 3:1
Vegetation	Suited to hydrologic regime and soil depth
Bypass/Flow Splitter	As necessary to ensure design flow or volume is not exceeded
Drawdown Time	Within 24 hrs

2.4 Important Construction Considerations

There are important construction guidelines that must be followed to prevent failure of the facility before it is even put into service. Some of the more common and easily undertaken measures to avoid mistakes include:

- It is imperative that bioretention facilities be protected from sediment laden inflows during site construction. Ideally, the facilities should be built as a last step and after the contributing drainage area has been fully stabilized.

- Construction traffic on the facility footprint should be avoided to minimize soil compaction. This is especially important for facilities that will employ infiltration.

- It may be helpful to rip or scarify the bottom of the facility 6-12 in to promote infiltration.

- Perform infiltration tests on a batch of the soil media to ensure it infiltrates at an acceptable rate. Multiple tests are necessary to achieve a stable infiltration rate that will be representative of what can be expected – the rate tends to decline with each test until an equilibrium rate is achieved. While a mix of the proper proportions of sand, fines, and organic matter should be sufficiently permeable, it is sometimes difficult to ensure that the material has been mixed in the correct proportions, and sieve analyses fail to account for the permeability effect of platy particle shapes (mica or leaf mulch can reduce permeability after several flood/dry cycles). Testing prior to placement can avoid the costly removal and replacement of material after the facility fails.

- Place the soil media in 12 inch lifts and flood to provide hydraulic compaction. Add additional material as necessary to ensure the proper design elevation is achieved.

- Provide irrigation of newly planted vegetation until sufficiently established (at least through 1 growing season). Also consider watering options during drought conditions in areas where aesthetics is a concern.

2.5 Operation and Maintenance

If properly designed and constructed, bioretention facilities require little maintenance to keep them functioning properly. Inspections during the first year following installation are of particular importance. Particular items to look for include:

- The most obvious sign of a problem is excessive ponding of water that takes longer than 24-48 hours to drain (faster time in urban, highly visible areas). If this occurs, it can generally be attributed to two causes:

    1) The filter media (or the underdrain) were not designed and/or installed properly.
    2) The media has been clogged with sediment after construction.

If proper procedures were followed during design and construction, then the second cause is most likely.

- Inspect inflow areas to see if a sediment accumulation is obvious on the surface of the facility. If there is evidence of sedimentation, inspect the side slopes of the facility, as well as the contributing watershed, to determine the source and correct as necessary. Remove accumulated sediment and replace mulch cover.

- Ensure the mulch layer is intact and completely covers the surface of the facility as it provides significant filtering benefits, trapping much of the incoming sediment loads. For urban settings with a higher potential for heavy metal deposition, replace the mulch on an annual basis.

- Inspect the vegetation and replace dead plants as necessary. Adjust plant species if it is determined a particular type is not doing well.

2.6 Performance Criteria

Bioretention facilities can provide effective water quality and volume reduction benefits. With the various design options regarding facility sizes and configurations comes differences in the anticipated removal rates. Generally speaking, smaller facilities provide lower efficiencies than larger, deeper facilities. The following chart provides anticipated ranges, with smaller, urban facilities at the lower end (note that pollutant removal represents total mass loading resulting from treatment as well as from volume reduction – Source: *VA SWM BMP Design Specifications*):

Table 2-2. Bioretention Range of Typical Performance

Parameter	% Reduction
Volume Reduction (1" Storm)	40 -80
Total Phosphorus (TP)	55 - 90
Total Nitrogen (TN)	64 - 90

2.7 Cost

A variety of sources and literature were reviewed to determine the average costs for bioretention system construction and materials. These costs vary based primarily on the type of application (i.e., residential vs. commercial or industrial site) and whether the project is a retrofit or new construction. Residential bioretention, or rain gardens, typically cost between $5 and $12 per square foot to install. Larger scale commercial, industrial, or institutional projects that involve more complex design, an underdrain system, amended soils, and use of heavy equipment may run more in the range of $15 to

$60 per square foot to install. Retrofit projects, especially in urban areas, will generally have even higher costs due to site constraints and existing infrastructure.[2]

2.8 Applicability to DC Water

Bioretention facilities can be designed and adapted to fit the available space and are, therefore, well suited for use in urban areas. They can provide significant volume and pollutant reductions and represent a good opportunity to reduce the occurrence of CSO events.

2.9 Detailed Design References

Detailed design methods are available in published documents and manuals that are periodically updated to keep abreast of advances in technology. While there are literally hundreds of such detailed design manuals, two are particularly clear and complete, and are from nearby regions:

- Virginia Department of Conservation and Recreation (DCR), Virginia Stormwater BMP Clearinghouse - http://vwrrc.vt.edu/SWC/StandardsSpecs.html.

- North Carolina Division of Water Quality, Stormwater Best Management Practices Manual - http://portal.ncdenr.org/web/wq/ws/su/bmp-manual.

It is important to make certain that the selected design options are acceptable to the District Department of the Environment (DDOE) prior to implementation and are in accordance with DDOE design guidance. DDOE is currently in the process of revising current guidance documents and adopting the runoff reduction methodology used by the Virginia Department of Conservation and Recreation (as communicated in an email from Rebecca Stack, DDOE, 3/19/12).

2.10 Example Applications

The following figures provide some typical schematics and photos of facilities that would be more relevant in confined, urban settings and, thus, would be more applicable to DC Water:

[2] Cost Estimate Sources: DC Department of the Environment Riversmart Program, Water Environment Research Foundation, U.S. EPA, Low Impact Development Center, Virginia Polytechnic Institute, Pennsylvania Department of Environmental Protection, Southeast Michigan Council of Governments

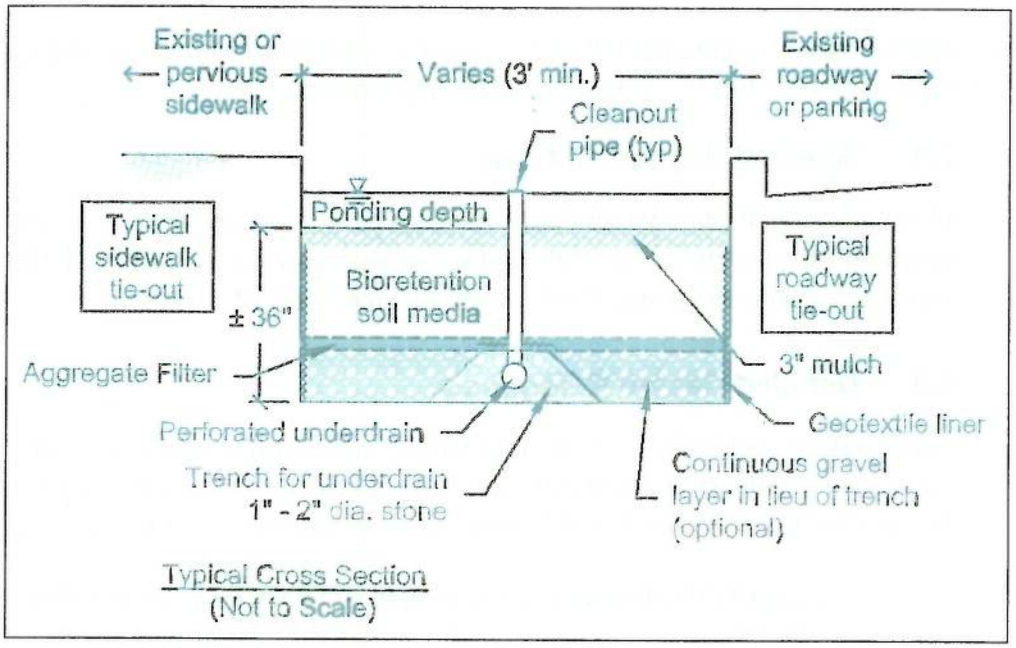

Figure 2-4. Schematic of a typical bioretention cell adjacent to a roadway. (Source: Wetland Studies and Solutions, Inc.)

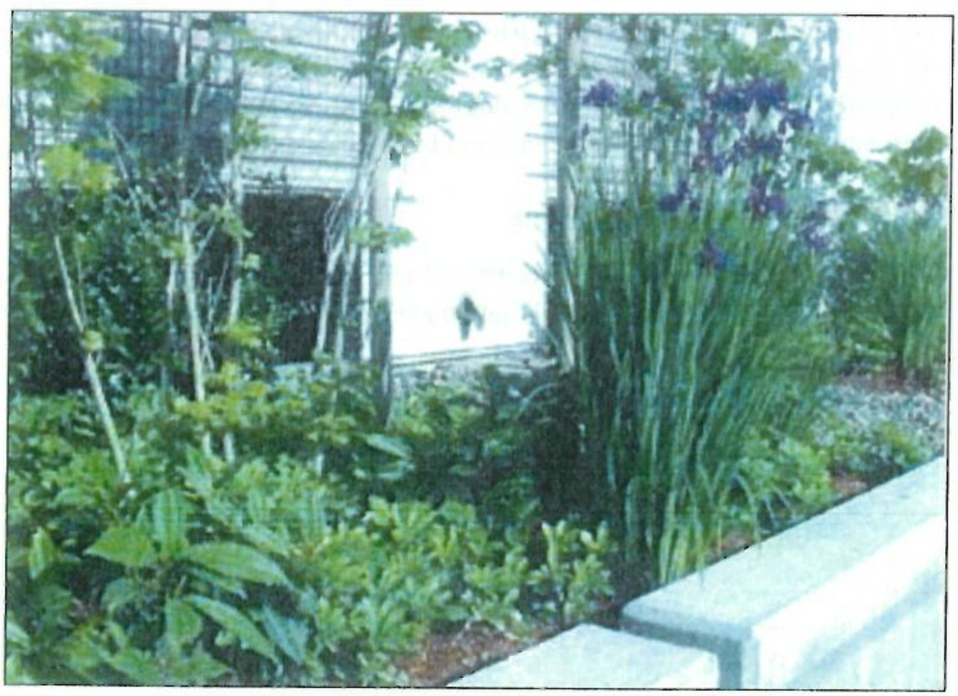

Figure 2-5. Typical bioretention planter box adjacent to a building. (Source: City of Portland SWM Manual)

Figure 2-6. Bioretention planters adjacent to a roadway in Richmond, VA. (Source: Wetland Studies and Solutions, Inc.)

Figure 2-7. Bioretention planter in an urban courtyard. (Source: Portland SWM Manual)

Figure 2-8. Bioretention in a parking lot island.
(Source: NCDENR Stormwater BMP Manual)

Figure 2-9. Bioretention facility treating parking lot and rooftop.
(Source: Wetland Studies and Solutions, Inc.)

3 Pervious Pavement

3.1 Description

Pervious Pavement can come in different forms, but generally provides the same type of function that replaces impervious, traditional paving surfaces with materials that provide the necessary structural support while allowing rainfall to infiltrate into the underlying gravel base and soil strata. The specific design of pervious pavement systems can vary, but there are basic elements that include:

- Surface (wearing) Course
- Leveling Course (not always necessary depending on the type of pavement)
- Aggregate Storage Layer (for structural support and water storage)
- Underdrain and/or Overflow Structure
- Filter Fabric or Choker Course

The basic types of pervious pavement include porous concrete, porous asphalt, interlocking concrete pavers, and various types of grid systems made of concrete or plastic that incorporate gravel (or soil and grass) in the void spaces. For the concrete and asphalt pavements, permeability is achieved through exclusion of fine aggregate in the pavement mixes – thereby creating a media with connected porous space. Concrete pavers rely on a portion of the surface area being open and filled with a porous material (gravel without fines).

For each type of pavement, water quality and quantity benefits are realized through filtration, storage, and infiltration of stormwater. However, given the additional requirement to provide structural paving surfaces, proper and careful siting and design is essential to the long term success and functionality of this practice. In addition to the structural and environmental benefits, pervious pavement systems can provide additional aesthetic appeal through the use of various color and pattern options that are available (primarily concrete pavers, although colored pervious concrete is also available).

Figure 3-1. Pervious paver shoulders along a residential street (Source: LID Manual for Michigan)

3.2 Feasibility Considerations

There are constraints related to the use of pervious pavements that must be considered to ensure long-term functionality is achieved. Some of these constraints relate to the structural function of the pavements and particular attention must be paid to them. Some of the more important considerations include:

3.2.1 Location

Pervious pavement is not intended for high speed roads. Although it can be designed to support heavy loads and/or heavy traffic volumes, it may be advisable to use conventional paving materials in the drive aisles with pervious pavement on the shoulders or in parking stalls.

3.2.2 Contributing Drainage Area

In general, pervious pavements are intended to provide treatment of the stormwater that falls directly on the surface. However, it is acceptable to receive runoff from adjacent, impervious areas (especially in instances where drive aisles are traditional pavement) that are no more than twice the area of the pervious pavement itself. Although not recommended, it is possible to have stable, pervious areas drain as sheet flow onto pervious pavements, provided there is effective filtering of organic matter and sediment to prevent clogging. Point discharges onto pervious pavements are not recommended as there is a high likelihood of localized clogging due to sediment influx.

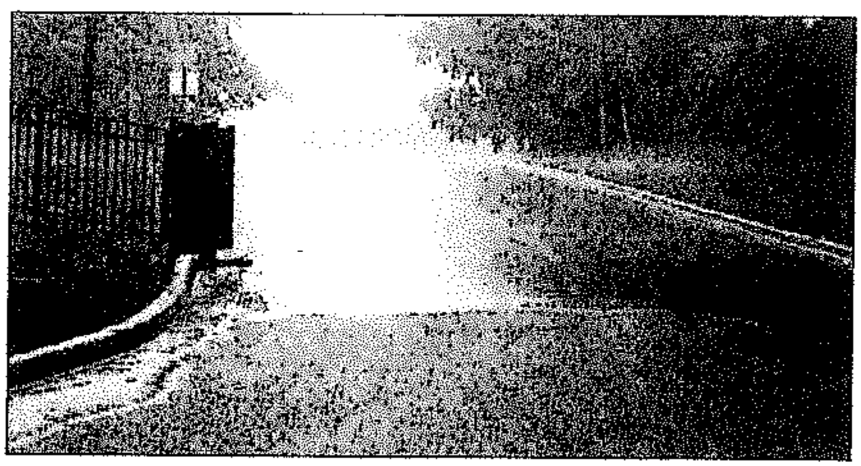

Figure 3-2. Run-on from traditional asphalt pavement. (Source: LID Manual for Michigan)

3.2.3 Available Space

A major benefit of the use of previous pavements is that they require no additional space as they can typically replace conventional paving materials wherever they are used on the site (with the exceptions of high speed or heavy load areas noted above).

3.2.4 Topography

For sites where the in-situ soils are sufficiently permeable, a soil (subgrade) slope of 0.5% or less is desirable to promote infiltration. For more steeply sloped applications, internal berms or baffles can provide effective "flattening" of the slope. Ideally, the flatter the overall pavement slope the better to not only aid infiltration, but to also minimize the chance of shifting of the pavement surface and/or sub-base. Slopes of several percent or less (up to a 5% maximum) are cited in the literature.

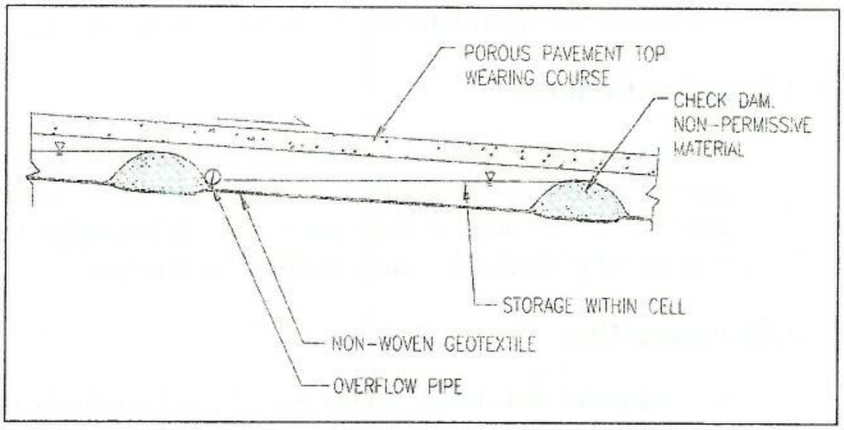

Figure 3-3. Schematic depicting internal berms for sloped applications. (Source: 2012 Draft LID Manual for Puget Sound)

3.2.5 Available Hydraulic Head

For systems draining to a stormwater conveyance through an underdrain, there must be a sufficient difference in elevation to make sure the underdrain flows freely and does not inhibit the flow through the pavement. A several foot difference in hydraulic head may be required. To aid in drainage, underdrains should be designed with a nominal positive slope of at least 0.5%.

3.2.6 In-Situ Soils

Low permeability of soils on the site does not inhibit the use of pervious pavement practices. Given that subgrades for pavements require structural support and become more compacted over time as a result of the intended use, requiring permeable in-situ soils would be problematic. Underdrains are thus acceptable and can be capped off to provide a back-up should in-situ infiltration rates worsen over time. As with bioretention practices, another option is to employ a raised underdrain outlet that provides for some storage to allow the opportunity for infiltration, but does not rely on it.

3.2.7 Water Table

It's important to make certain that the seasonably high groundwater elevation is a minimum of 2 ft below the bottom of the pavement. This will inhibit the potential for groundwater contamination, as well as the potential for high groundwater levels to inhibit the proper draining of the pavement subgrade. Whereas ponding in other GI Technology applications may occasionally be acceptable, making certain this does not occur on paved surfaces is of particular importance.

3.2.8 Pollutant Hotspots

As with other infiltration practices, use of pervious pavements in areas where stormwater hotspots are likely to drain to the pavements is discouraged.

3.2.9 Utility Conflicts

Given that many utilities are located adjacent to or within paved areas, particular care to consider their locations should be exercised. Utilities may be located under pervious pavement areas, but certain utilities such as electric and communication need special waterproof protection if located within the gravel bed.

3.2.10 Freeze/Thaw

It is suggested that storage volume for the 10-yr storm be provided in the gravel base below the pavement material to minimize freeze/thaw damage.

3.2.11 Location

Care should be taken to minimize a hydraulic connection to adjacent buildings. Required setbacks will largely depend on the scale of the pervious pavement application. Placement adjacent to overhanging trees or other vegetation should be avoided as this becomes a source for potential clogging.

3.2.12 Maintenance Commitment

The owner of the pervious pavement must be made aware of and be willing to accept and perform the necessary maintenance activities to keep the pavement functioning properly. This includes regular activities, such as vacuum sweeping, as well as making certain that activities that are often associated with the maintenance of traditional pavement, such as the application of sand and salt in winter or sealing or recoating, are strictly prohibited. The frequency of vacuum sweeping can be adjusted based upon site specific loading rates of debris, dirt, and leaves.

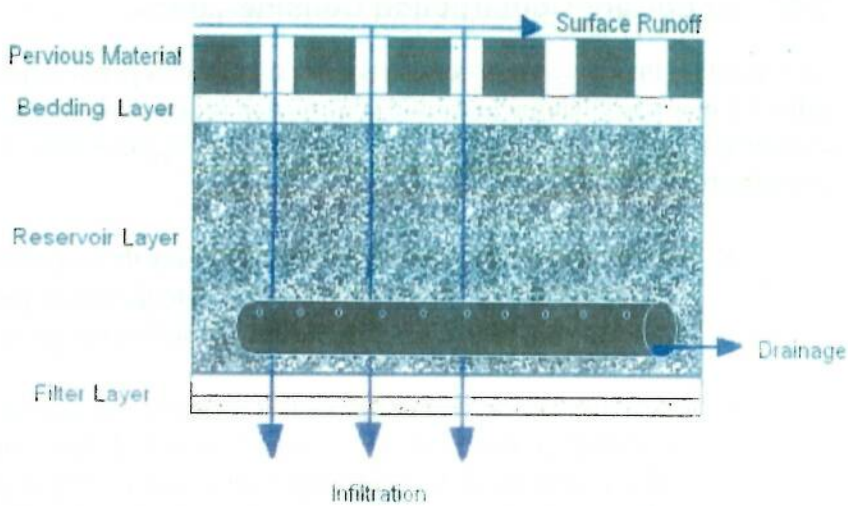

Figure 3-4. Typical cross-section of pervious pavement.
(Source: VA SWM BMP Design Specifications)

3.3 Basic Design Elements

In addition to the design of pervious pavements to meet the desired hydraulic performance, the proper design to meet the necessary structural requirements of the intended application is essential. While the details of structural pavement design are beyond the scope of this manual, there are some basic design parameters to consider, as summarized as follows:

Table 3-1. Pervious Pavement Typical Design Elements

Design Element	Typical Values
Drainage Area	Limit run-on from other areas; provide pre-treatment if unavoidable.
Surface Course	Concrete, Asphalt, Concrete Pavers, Reinforced Grid Systems
Surface Course Thickness	Concrete: 5-8" Asphalt: 3-4" Pavers: 3" All are typical values that can vary.
Base Course	Uniformly graded, clean, washed crushed stone (typically No. 57 stone).
Base Course Depth	Typically 8"to 36", depending on structural and SWM requirements.
Longevity	Concrete: 20-30 yrs Asphalt: 15-20 yrs Pavers: 20-30 yrs
In-Situ Infiltration Rate	> 0.5 in/hr (without underdrain). Do not use over fill soils without a liner.
Depth to Groundwater	2 ft minimum, up to 4 ft preferable to prevent ponding on pavement surface.
Underdrain	4 in schedule 40 PVC with 3/8 in perforations
Geotextile Fabric	Impermeable liner required over fill or areas with high potential for contamination.
Pavement Slope	Bottom of subgrade - 0.5% or less. Surface – flat as possible, but no more than 5%.
Overflow Protection	Various design options to prevent surface ponding in significant (100 year) events. Design should prevent the upper 6 in of the pavement from becoming saturated.
Surface Clogging	Repave or install drop inlets (Concrete and Asphalt). Replace stone jointing materials (Pavers).

3.4 Important Construction Considerations

As with other infiltration practices, long term success of a pervious pavement facility can only be achieved by close attention to careful construction procedures. Many failures can be directly attributed to a failure to adhere to important construction guidelines. Some of the most important considerations include:

- Pervious pavement (as well as other practices that require infiltration) should be installed toward the end of the construction period, to the extent possible, to prevent sediment or landscaping soils/mulch deposition on either the pavement bed or surface.

- Pervious pavement can be placed on locations where temporary sediment basins or traps were employed, provided they are not excavated any closer than 24 in from the planned bottom elevation of the pavement reservoir layer. Upon removal of the basin and sediments, the bed can be excavated to its final grade. This same general approach can be used as the overall site is being developed – do not grade the pavement bed to the final elevation until adjacent site areas are fully stabilized.

- Avoid over-compaction of the subgrade to the extent practicable through the use of proper equipment and construction techniques. If possible, limit equipment tracking over the bed by excavating from the side. In larger applications, the site can be split into smaller, temporary cells that will facilitate this approach. Upon completion, scarify the bottom of the pavement bed 6-12 in to promote infiltration.

- Install a choker course between the native soil and aggregate bedding layer (typically comprised of a 2-4 in layer of No. 8 stone covered by 6-8 in layer of course sand). While a geotextile membrane can be used for this purpose, they can in some instances clog (if not correctly selected) more readily than the choker course.

- Inspect the aggregate used for the reservoir and bedding material to ensure it is washed and is free of fines that can lead to clogging.

- Placement of pervious pavement requires specialized skills and experience and should only be performed by qualified and experienced contractors.

Figure 3-5. Placement of pervious concrete.
(Source: Wetland Studies and Solutions, Inc.)

3.5 Operation and Maintenance

If properly designed and constructed, pervious pavements require manageable amounts of maintenance and good housekeeping practices to keep them functioning properly. These include:

- Vacuum the pavement once or twice a year to remove debris, leaves, or fines and other debris. In areas of high usage or significant tree cover, this can be necessary 4-12 times per year.

- Prevent tracking of sediments by construction or other vehicles to the extent practicable. Do not store mulch, topsoil, or any other materials that contain fines on the pavement surface. Remove any sediment deposition as soon as possible to prevent it from being ground into the pavement surface.

- Inspect adjacent areas to ensure vegetation coverage is complete and stabilize any areas of bare soil that may contribute sediment.

- Do not use sand or other abrasives on the pervious pavement or on other adjacent surfaces that may allow it to migrate to the pervious pavement.

Figure 3-6. Red maple seeds lodged in pores of permeable asphalt. (Source: Wetland Studies and Solutions, Inc.)

- For large pervious pavement applications, small damaged areas can be repaired with conventional paving materials without a significant loss of functionality. However, the potential for reduced performance should be considered when deciding whether to replace larger damaged areas with new pervious pavements. Repair of concrete pavers can be accomplished by removal and replacement of the blocks and fines within the open spaces.

- Sealants must never be used (primarily an issue for pervious asphalt applications).

- While many publications indicate that pervious pavements actually tend to promote snow melt, experience at Wetland Studies and Solutions, Inc. (WSSI) indicates the opposite can be true, as shown below. This should be taken into account if this could be an issue for the particular application. While deicers can be used (preferably other than salt), use should be minimized to the extent practical due to the potential for groundwater infiltration. Our experience is that in freezing rain or sleet, pervious pavements freeze more rapidly than conventional pavements, leading to potentially hazardous conditions.

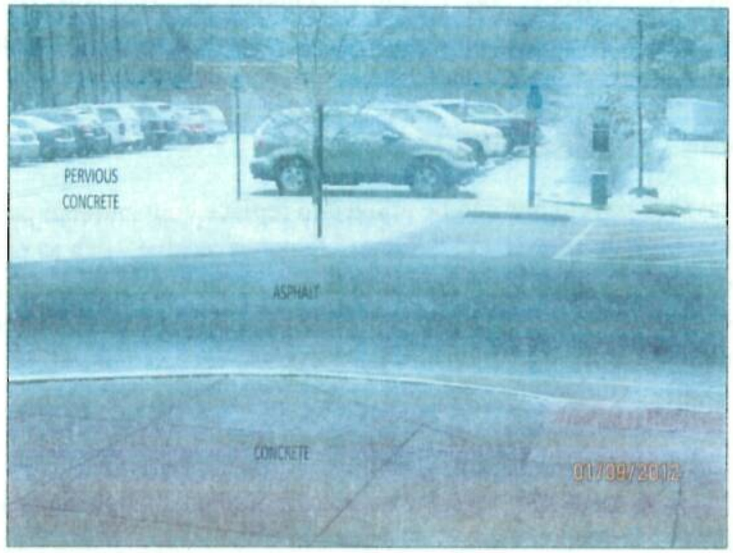

Figure 3-7. Pervious concrete parking lot in snow – note coverage compared to conventional paving materials. (Source: Wetland Studies and Solutions, Inc.)

3.6 Performance Criteria

Pervious pavements can provide effective water quality and volume reduction benefits. With the various design options regarding facility sizes and configurations comes differences in the anticipated removal rates. Generally speaking, smaller facilities provide lower efficiencies than larger, deeper facilities. The following chart provides anticipated ranges, with smaller, urban facilities at the lower end (note that pollutant removal represents total mass loading resulting from treatment as well as from volume reduction – Source: *VA SWM BMP Design Specifications*):

Table 3-2. Pervious Pavement Range of Typical Performance

Parameter	% Reduction
Volume Reduction (1" Storm)	45 -75
Total Phosphorus (TP)	59 - 81
Total Nitrogen (TN)	59 - 81

3.7 Cost

A variety of sources and literature were reviewed to determine the average costs for pervious pavement construction and materials. These costs vary depending on the technology employed and materials used. Generally, these applications range between $2 and $15 per square foot. Porous asphalt is the least expensive application (between $0.60 and $7 per square foot) and some research cites these costs as only 15% to 25% higher than standard asphalt costs. Pervious concrete is slightly more expensive at $2 to $13 per square foot. Pervious pavers are generally the most expensive application and range between $6 and $15 per square foot.[3]

3.8 Applicability to DC Water

Pervious pavements can be utilized to replace conventional paving materials in many applications where traffic speeds and volumes are not excessive, such as parking lots, roadway shoulders, alleys, courtyards, etc. They have the potential to provide substantial volume reductions, particularly when designed with a thicker gravel base to provide storage. Volume reduction and timing of runoff can help reduce the occurrence of CSO events.

3.9 Detailed Design References

Detailed design options are available in published documents and manuals that are periodically updated to keep abreast of advances in technology. While there are literally hundreds of such detailed design manuals, two are particularly clear and complete, and are from nearby regions:

- Virginia Department of Conservation and Recreation (DCR), Virginia Stormwater BMP Clearinghouse - http://vwrrc.vt.edu/SWC/StandardsSpecs.html.

- North Carolina Division of Water Quality, Stormwater Best Management Practices Manual - http://portal.ncdenr.org/web/wq/ws/su/bmp-manual.

It is important to make certain that the selected design options are acceptable to the District Department of the Environment (DDOE) prior to implementation and are in accordance with DDOE design guidance. DDOE is currently in the process of revising current guidance and adopting the runoff reduction methodology used by the Virginia Department of Conservation and Recreation (as communicated in an email from Rebecca Stack, DDOE, 3/19/12).

3.10 Example Applications

The following provide some typical schematics and photos of facilities that would be more relevant in confined, urban settings, and thus would be more applicable to DC Water:

[3] Cost Estimate Sources: DC Department of the Environment Riversmart Program, Water Environment Research Foundation, U.S. EPA, Low Impact Development Center, Maryland Department of the Environment, Fairfax County, City of Portland

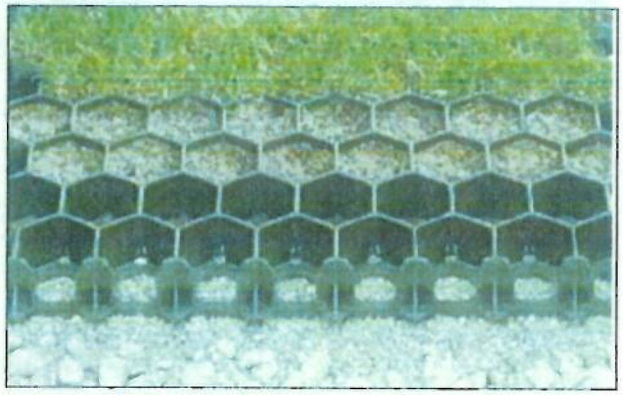

Figure 3-8. Reinforced grid system.
(Source: SWM Handbook for Northern Kentucky)

Figure 3-9. Pervious concrete in parking lot stalls.
(Source: SWM Handbook for Northern Kentucky)

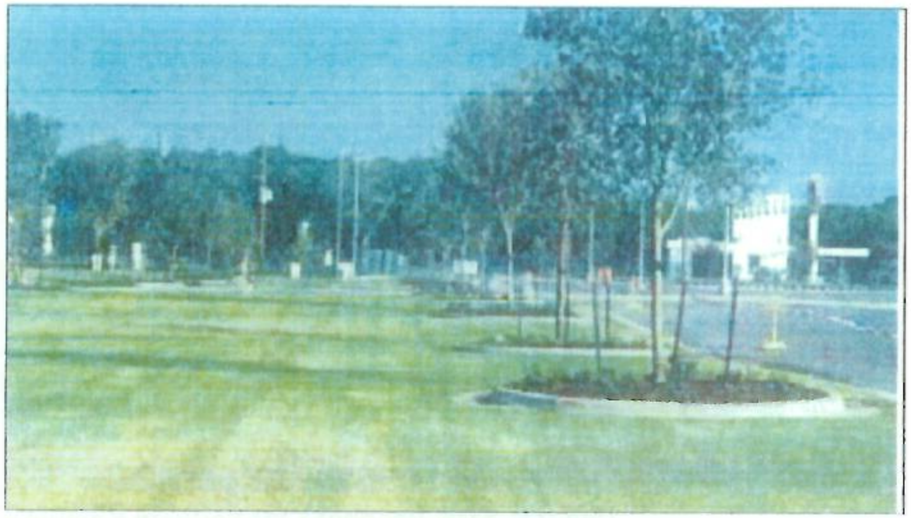

Figure 3-10. Reinforced turf used for overflow parking.
(Source: LID Manual for Michigan)

Figure 3-11. Colored pervious concrete.
(Source: LID Manual for Michigan)

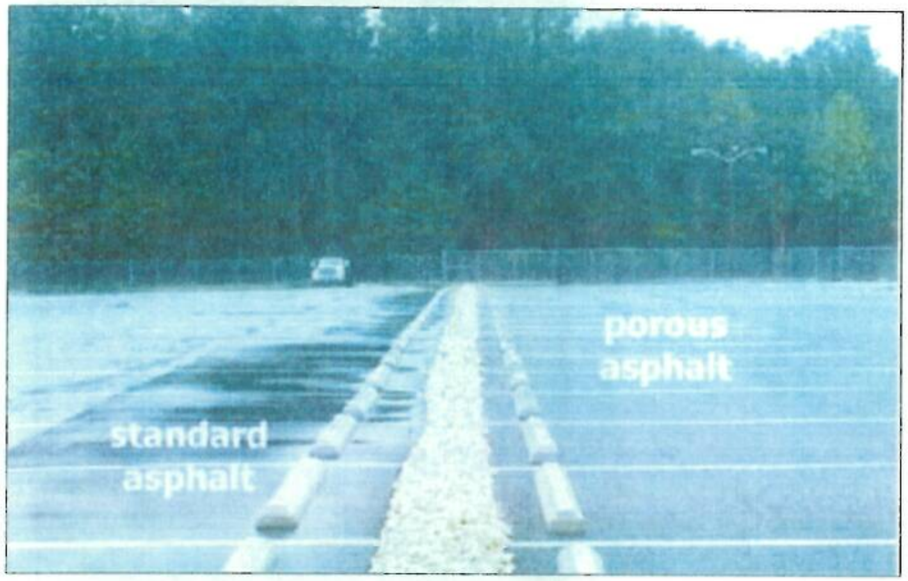

**Figure 3-12. Porous and conventional asphalt.
(Source: LID Manual for Michigan)**

**Figure 3-13. Pervious concrete residential street.
(Source: City of Seattle Stormwater Manual)**

Figure 3-14. Pervious pavers in parking area. (Source: Wetland Studies and Solutions, Inc.)

4 Soil System Detention

4.1 Description

A significant contributing factor in the degradation of water quality and increase in stormwater runoff volume in urban situations is the compaction of soil. Often by necessity, soils in developed areas require compaction in order to provide support for infrastructure like roads, parking lots, sidewalks, utilities, etc. Thus, even when not covered with impermeable asphalt or concrete, soils in urban settings often behave much like impermeable surfaces and provide few of the benefits of an undisturbed soil profile. These benefits begin with the ability to infiltrate stormwater, which provides the opportunity for nutrient, sediment, and pollutant adsorption, biofiltration, the transmission and storage of water within the soil, the microbial decomposition and uptake of pollutants. A "healthy" soil profile also promotes vigorous vegetation growth, mitigating the increase in runoff volumes through evapotranspiration. Healthy and robust vegetation also reduces pollution through a reduction in the amount of fertilizers, herbicides, and pesticides that must be used to try to keep plants growing in harsh, urban settings.

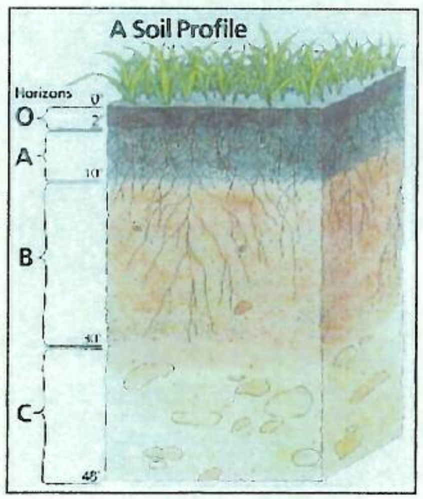

Figure 4-1. A healthy soil profile.
(Source: LID Manual for Michigan)

There are several options to provide for and/or restore many of the lost functions of a healthy, uncompacted soil profile. These options include:

4.1.1 Soil Amendments

Soil amendments involve the physical mixing of composted materials into compacted soils in order to improve the soil porosity and to incorporate organic matter to facilitate plant growth. Amended soils retain more water, thereby reducing runoff volumes, and support vigorous plant growth. The depth to which the soil is amended is dependent upon the contributing impervious area (maximum of 100% of the amended soil area) and is recommended to be from 6 to 24".

4.1.2 Structural Soils

Structural soils were developed at Cornell University and are sold under the trade name CU-Structural Soil™. Since its original development, other products have become available, such as Stalite Structural Soil. Structural soils can be used as a base under pavements to provide structural support while also providing an effective growing medium to facilitate and enhance the growth of adjacent trees. The reservoir can also be sized to accommodate virtually any size storm event (subject to site constraints). CU-Structural Soils™ consist of uniformly graded, crushed rock aggregate that is "coated" with a heavy clay loam or loam through the use of a tackifier. Carolina Stalite is a similar product except the aggregate is comprised of a lightweight expanded slate that, because of the rough surface texture, does not require a tackifier. The chemical properties of the expanded slate also allow the use of a soil with a lower clay content (a sandy clay loam is specified). For both products, the rock comprises the structural framework to support the pavement loads while the voids and soil provide a media that allows for air, water, and nutrients to support healthy root growth.

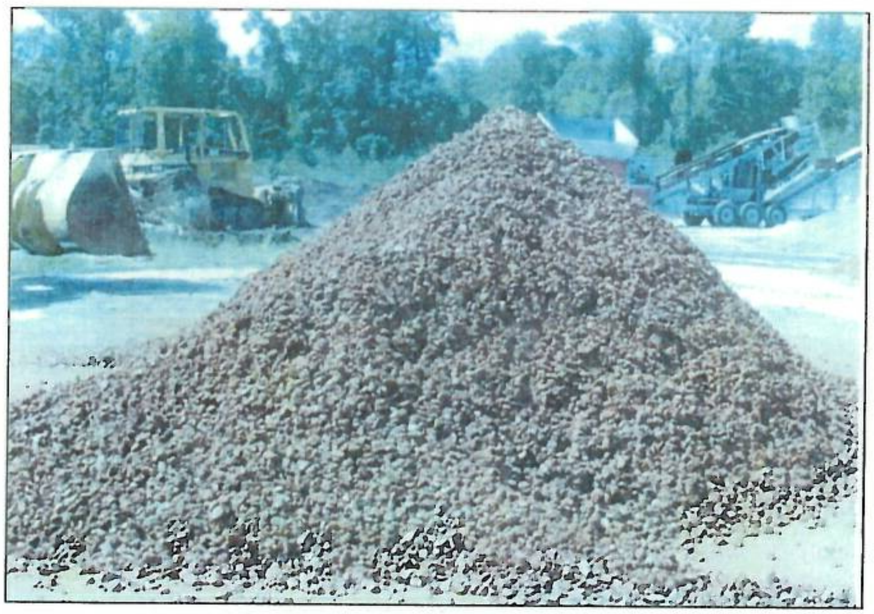

Figure 4-2. CU-Structural Soil™
(Source: Cornell University – Urban Horticulture Institute)

4.1.3 Silva Cells

Silva Cells (manufactured by Deep Root Partners, L.P.), have a similar function as structural soils to facilitate tree growth while providing support for pavements. This system differs in that the structural integrity is provided by a fiberglass/plastic framework (with galvanized tubes to provide additional structural integrity) that provides room for soil within the posts of the framework. Since the framework provides the necessary structural support, the soils can be compacted to the optimum density to facilitate plant growth. The soil media can also provide stormwater detention.

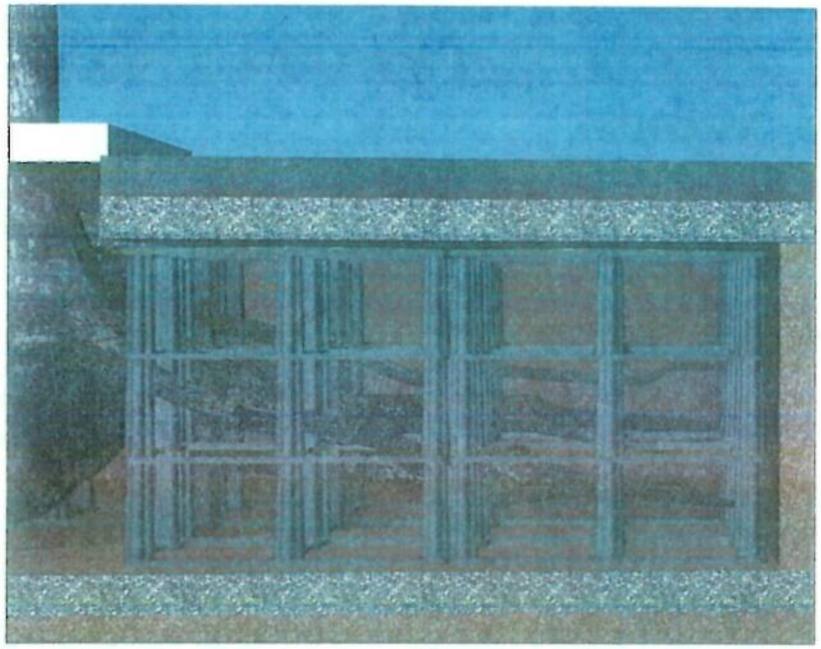

Figure 4-3. Silva Cell under roadway (soil not shown for clarity)
(Source: Deep Root Partners L.P.)

4.2 Feasibility Considerations: Soil Amendments

The use of these soil practices is largely dictated by the feasibility of being able to work within the footprint where it is to be implemented. There are considerations that should be taken into account as discussed below:

4.2.1 Location

Soil amendments can be applied wherever disturbance of the top 6-24-in of the soil can be performed without damage to utilities or existing tree roots from adjacent trees. Potential uses include residential and/or commercial lawns to enhance rooftop disconnection or to improve infiltration in compacted soils. They can also be employed in vegetated swales (especially along highway rights-of-way) or filter strips to improve their runoff reduction (and associated pollutant removal) performance.

4.2.2 Contributing Drainage Area

The contributing drainage area is not necessarily limited, especially in applications such as a roadside ditch (where the hydraulic conveyance of the ditch would dictate). In general, however, it is recommended that the amount of impervious area draining to the practice be limited to twice that of the surface area of the amended soils. The less the amount of impervious area, the shallower the necessary depth of the soil amendment.

4.2.3 Available Space

No additional space is required as they can be employed wherever vegetated areas exist or are proposed. Residential and commercial lawns represent the most likely locations.

4.2.4 Topography

Soil amendments are not as effective in areas where the slope exceeds 5%. Slopes greater than 5% may require terracing and the practice is not recommended for slopes greater than 10%.

4.2.5 In-Situ Soils

Unlike other practices where poor soils may limit their use, soil amendments are generally not necessary in well draining soils (hydrologic soil groups A and B).

4.2.6 Utility Conflicts

Any required excavation must consider the possibility of utility conflicts.

4.3 Feasibility Considerations: Structural Soil or Silva Cells

4.3.1 Location

Both of these proprietary practices can be employed wherever trees are planted adjacent to or within parking lots, sidewalks, courtyards, low-use access roads, or any other location where paved surfaces limit suitable soil volumes to support healthy tree growth. Structural soils have also been utilized to provide reinforced turf areas that allows for heavy loads while maintaining healthy turf growth.

4.3.2 Contributing Drainage Area

The primary benefit of these practices is to support the vigorous and healthy growth of trees in confined, urban settings where sufficient volumes of soil to allow root growth are often lacking. However, the reservoir size can also be designed to accommodate storms of virtually any size (depending on the size of the contributing drainage area). Care should be taken to ensure the growing media can contain the runoff without prolonged inundation of the tree roots (more than 48 hours). Underdrains may be required when underlying soils are not sufficiently permeable. Care must also be taken to ensure water does not rise to the level of the pavement surface, as discussed in Chapter 2 – Pervious Pavements.

4.3.3 Available Space

No additional space is required as they can be placed wherever pavement exists or proposed adjacent to tree planting areas.

4.3.4 Topography

No restrictions. Can be used wherever trees are intended adjacent to paved areas. For very steep applications, the bottom of the storage reservoir can be terraced to promote better infiltration (where applicable).

4.3.5 In-Situ Soils

In soils that do not drain well, it may be necessary to provide an underdrain. For structural soil applications, the infiltration rate is very high and thus care must be taken to ensure that the tree roots are not inundated for extended periods (more than 48 hours). This can be accomplished by limiting the contributing drainage area, providing an underdrain, or by ensuring the "pit" is sufficiently deep to accept the inflow without unacceptable inundation. Silva Cell soils use available soils (silt/loam is preferable) and are compacted to the optimal density to promote tree growth (i.e., compaction is not necessary for structural support). Thus, the infiltration rate will be much slower and thus may not require an underdrain.

4.3.6 Water Table

Use in areas with high water tables (within 2 ft of the bottom of the media) could impact tree growth and thus should be avoided, unless trees suited to this condition are selected or it is determined the soil depth is sufficient for the particular tree species.

4.3.7 Utility Conflicts

Any required excavation must consider the possibility of utility conflicts. Local utility owners should be consulted regarding requirements associated with any required horizontal or vertical clearance or other special measures that may be required. The fact that utilities pass through these practices is not problematic, as long as it is approved by the utility owner.

4.3.8 Set-Backs

Care should be taken to minimize a hydraulic connection to adjacent buildings without proper waterproof protection. A distance of 10 ft from buildings is generally recommended for most practices where detention is provided.

4.4 Basic Design Elements

There are recommended design specifications for soil amendments. More detailed information can be obtained in the literature cited in Section 4.9. However, a summary is provided in the following table (Source: *VA SWM BMP Design Specifications*):

Table 4-1. Soil System Detention Typical Design Elements

Design Element	Typical Values
Drainage Area	Limit run-on from impervious areas to a maximum of twice the area of the

	amended soils.
Soil Testing	Recommended before soil amendment to determine if it is required, and after to determine if the desired goals were achieved.
Recommended Compost Depth and Tilling Depth (lower for B soils, higher for C/D soils)	Varies depending on the ratio of impervious area (IA) to the surface area of the amended soils (SA). • For a ratio of 0.00 - 2" to 4" of compost tilled to a depth of 6" to 10" • For a ratio of 0.50 - 3" to 6" of compost tilled to a depth of 8" to 12" • For a ratio of 0.75 - 4" to 8" of compost tilled to a depth of 15" to 18" • For a ratio of 1.00 - 6" to 10" of compost tilled to a depth of 18" to 24"
Compost Specifications	Provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program. Local providers can be found at www.compostingcouncil.org.

4.4.1 Structural Soils

Specific design information for these proprietary products can be found at the websites provided in Section 4.9. A few technical details are provided in the following table:

Table 4-2. Typical Design Elements for CU Structural Soils™ (CU) and Stalite Structural Soils (SS)

Design Element	Typical Values
Structural Framework	CU: Crushed stone, ¾" to 1 ½" SS: Expanded slate, ¾" to #4 screen size
Soil	CU: Approved heavy clay loam or loam, with a minimum clay content of 20%, 2-5% organic matter. SS: Approved sandy clay loam
Tackifier	CU: Gelscape® hydrogel SS: None required
Compaction	Both: To 95% standard proctor
Underdrain	The need must be assessed to prevent unacceptable inundation of tree roots.

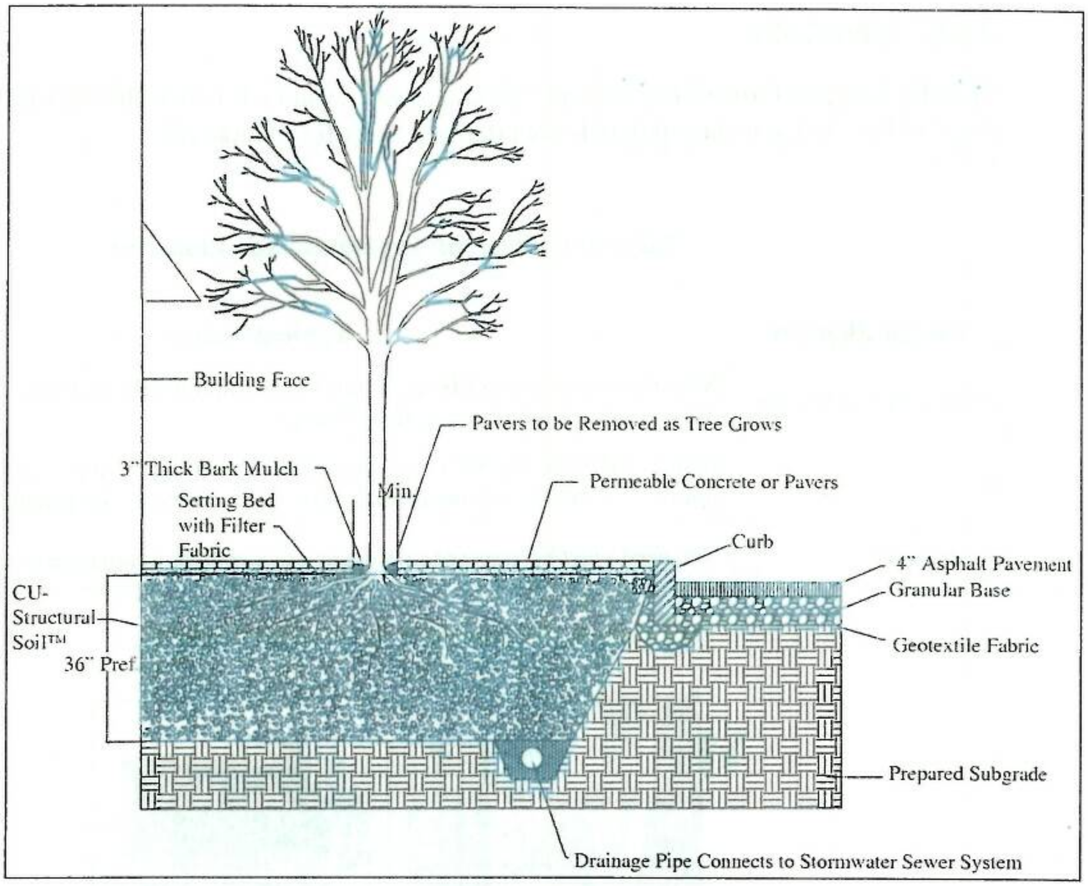

Figure 4-4. Typical CU-Structural Soil™ application incorporating pervious pavement. (Source: Cornell University – Urban Horticulture Institute)

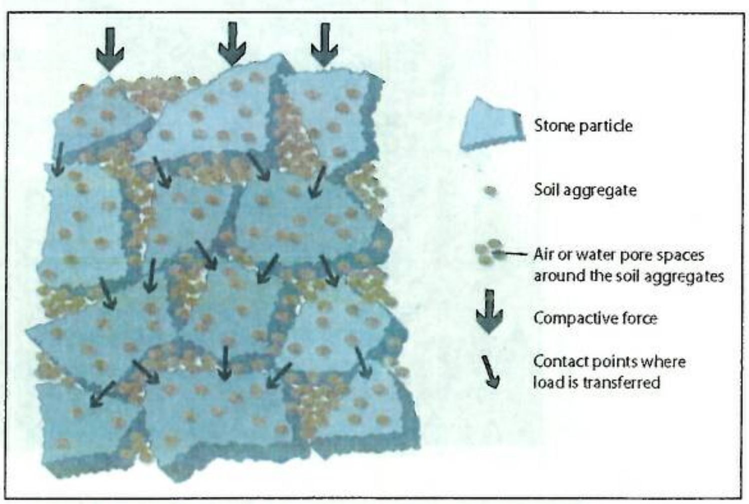

Figure 4-5. Schematic of structural soil composition. (Source: Virginia Tech – Susan Downing Day and Sarah Beth Dickinson)

4.4.2 Silva Cells

Specific design information for this proprietary product can be found at the website provided in Section 4.8. A few technical details are provided in the following table:

Table 4-3. Silva Cell Typical Design Elements

Design Element	Typical Values
Structural Framework	Modules consisting of fiberglass reinforced, chemically-coupled, impact modified polypropylene and galvanized steel tubes
Soil	Framework provides 92% void space that is filled and compacted with soil to provide optimal conditions for tree growth only – not necessary for structural support.
Underdrain	The need must be assessed to prevent unacceptable inundation of tree roots.

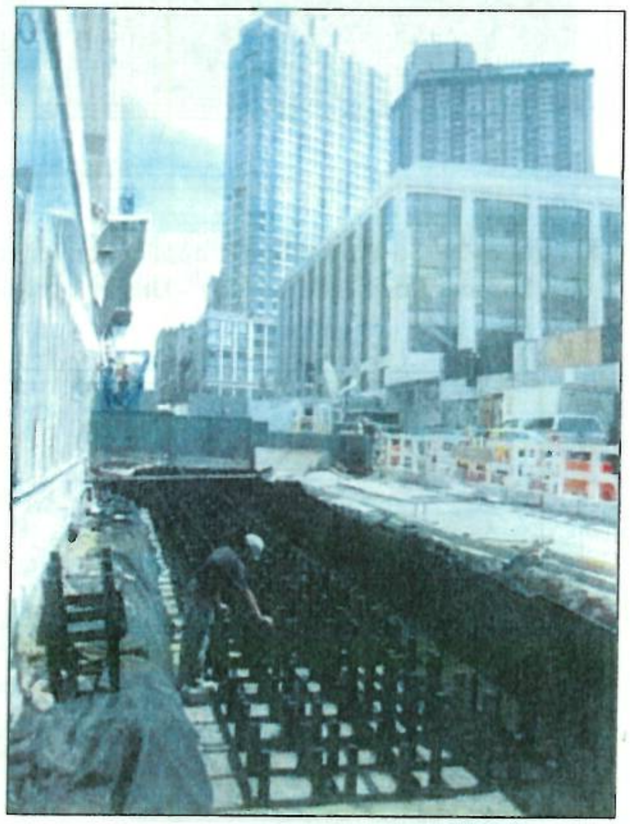

Figure 4-5. Installation of Silva Cells at Lincoln Center (Source: Deep Root Partners L.P.)

4.5 Important Construction Considerations

Recommended construction practices for the proprietary soil systems are available from the sources cited in Section 4.9. Some suggestions for application of soil amendments are provided below:

- Soils should be dry prior to tilling.
- Confirm there are no utility or tree root conflicts prior to soil disturbance.
- For smaller applications in residential lawns to enhance downspout disconnections, soil to be tilled with a small roto-tiller to the specified depth.
- For larger applications, soils to be ripped with solid shank ripper to the specified depth (2-3 ft if possible). Silt fencing may be required.
- Add compost at the specified rate and roto-till into the surface.
- Level the surface and cover with seed and mulch or sod to establish grass cover as quickly as possible. Test the soil to determine if lime is necessary and provide irrigation until the vegetation is well established.

4.6 Operation and Maintenance

Specifics regarding operation and maintenance of the proprietary soil systems can be found in the sources cited in Section 4.9. There are few required maintenance items associated with the care of soil amendments beyond initial efforts to ensure vegetation becomes well established:

- Inspect after large rain events for the first 6 months to ensure there is no erosion. Repair and re-seed any bare areas as necessary.
- Water as necessary for the first growing season until a vigorous stand of vegetation is achieved.
- Make certain the owners of the amended soil areas are aware of the practice and the goals behind keeping the area from becoming overly compacted.

4.7 Performance Criteria

Soil amendments act to increase the level of pollutant removal performance when used in conjunction with other practices. Estimates are provided in the following table Source: *VA SWM BMP Design Specifications*):

Table 4-4. Soil Amendments Range of Typical Performance Associated with Listed Practices

Soil Amendments with…	% Reduction[1]	
	No Soil Amendment	With Soil Amendment
Rooftop Disconnection	25	50
Filter Strip	Always recommended	50
Grass Swale	10	30

[1] Represents level of volume reduction (1" storm) and associated reduction in pollutant load as a result of this volume reduction (i.e. no BMP treatment provided).

It would be expected that the proprietary soil systems would provide similar removal efficiencies as bioretention or pervious pavement practices as they function in a similar manner. Thus, estimates of the potential removal rates that can be expected are provided in the following table (Source: *VA SWM BMP Design Specifications*):

Table 4-5. Proprietary Soil Systems Range of Estimated Performance

Parameter	% Reduction
Volume Reduction (1" Storm)	40 -80
Total Phosphorus (TP)	55 - 90
Total Nitrogen (TN)	40 - 90

4.8 Cost

A variety of sources and literature were reviewed to determine the average costs for soil system detention construction and materials. The cost of implementing soils amendments varies based primarily on the size of the project and the land use of the project area. Suburban or agricultural soil amendment projects applied to larger tracts of land are very inexpensive and can be implemented for as little as $0.10 to $0.75 per square foot. In more urban settings or smaller plots of land, soil amendments will typically cost between $1 and $5 per square foot to implement.

CU structural soils are generally sold for $40 to $47 per ton. Silva cell installation (not including surrounding paving or plant material) typically costs between $14 and $18 per cubic foot.[4]

4.9 Applicability to DC Water

Soil amendments would be applicable to DC Water as they can be applied in any area where vegetated, compacted soils exist and trees and/or utilities are not in conflict. Application in residential lots, parks, and cemeteries may be of particular benefit, especially if combined with

[4] Cost Estimate Sources: Virginia Polytechnic Institute, Fairfax County, Pennsylvania Department of Environmental Protection, Low Impact Development Center, Southeast Michigan Council of Governments, City of Redmond, Cornell University, Deep Root Partners, L.P.

rooftop disconnection, rain barrels, or other practices. Amended soils effectively hold and treat stormwater runoff, reducing the volume as well as pollutant loading.

Structural soil systems have the potential to provide a significant benefit to DC Water. This benefit is two-fold: first, structural soils can be employed under paved areas (sidewalks, courtyards, parking lots, roadway shoulders, etc.) and can include a reservoir capable of storing virtually any sized rainfall event (within the limitations of specific site constraints). They can also be effectively combined with pervious pavements (pavers, concrete, and/or asphalt) to facilitate infiltration of stormwater runoff. The stormwater management potential for these systems can provide beneficial reductions in stormwater volumes, as well as delays in the timing of the runoff – both can assist in reducing the occurrence of CSO events.

Secondly, unlike the use of other practices that provide detention in gravel reservoirs or soil (such as pervious pavements), these systems also provide an effective means for growing trees in harsh, urban environments. Healthy urban trees provide essential environmental, cultural, and aesthetic benefits. In addition, vigorous and healthy trees can transpire significant amounts of water during the growing season (up to 200 gallons per day for a mature tree on a hot day). However, urban trees decline when the limited room for root growth is depleted. Structural soils can provide the necessary media to allow roots to expand under pavements, enabling impermeable hardscapes and healthy trees to effectively co-exist.

4.10 Detailed Design References

Detailed design options are available in published documents and manuals that are periodically updated to keep abreast of advances in technology. These include the following sources:

- Virginia Department of Conservation and Recreation (DCR), Virginia Stormwater BMP Clearinghouse - http://vwrrc.vt.edu/SWC/StandardsSpecs.html.

- For CU Structural Soils™: Urban Horticulture Institute at Cornell University - http://www.hort.cornell.edu/uhi/outreach/index.htm#soil .

- For Silva Cells: Deep Root Partners, L.P. - http://www.deeproot.com/products/silva-cell/silva-cell-overview.html

- For Stalite Structural Soils - http://permatill.com

It is important to make certain the selected design options are acceptable to the District Department of the Environment (DDOE) prior to implementation and are in accordance with DDOE design guidance. DDOE is currently in the process of revising current guidance and adopting the runoff reduction methodology used by the Virginia Department of Conservation and Recreation (as communicated in an email from Rebecca Stack, DDOE, 3/19/12).

4.11 Example Applications

The following provide some typical schematics and photos of applications of the soil system detention practices:

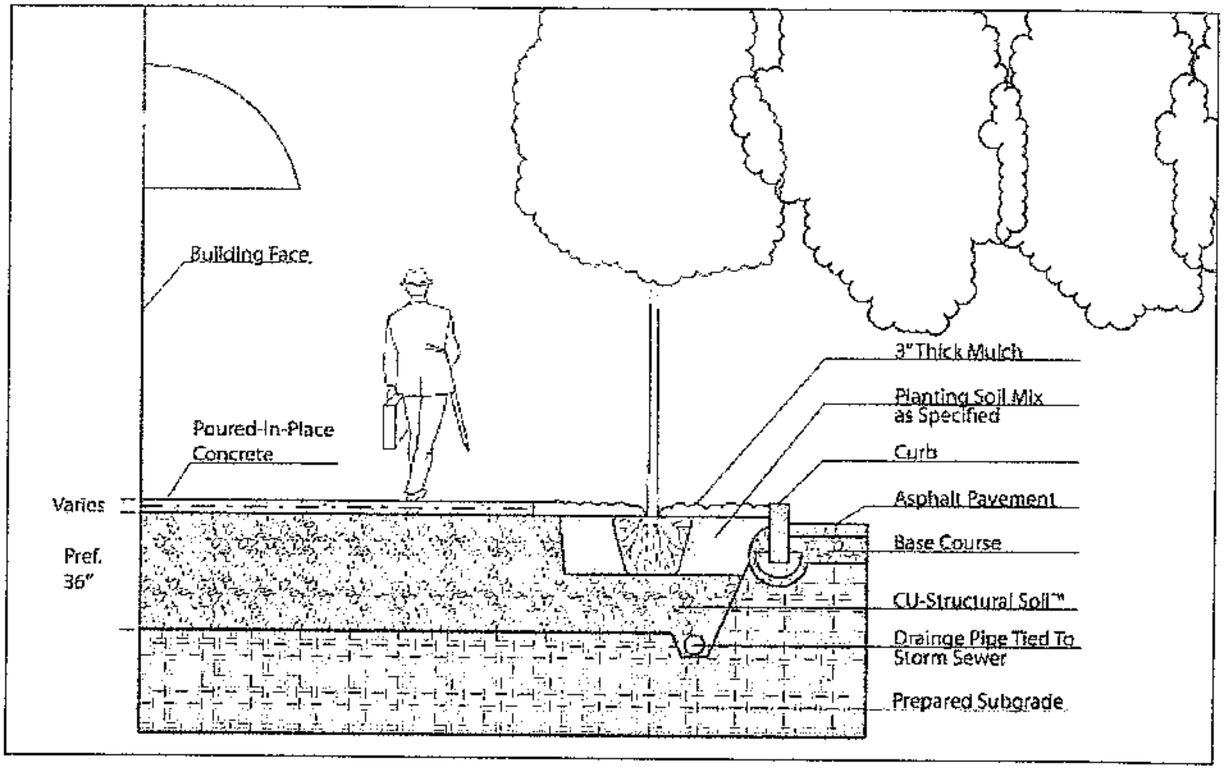

Figure 4-6. Typical CU-Structural Soil™ application. (Source: Cornell University – Urban Horticulture Institute)

Figure 4-7. Structural soil adjacent to a building.
(Source: Cornell University – Urban Horticulture Institute)

Figure 4-8. Utilities placed within Silva Cells.
(Source: Deep Root Partners L.P.)

Figure 4-9. Silva Cells adjacent to a roadway.
(Source: Deep Root Partners L.P.)

Figure 4-10. View of amended soils.
(Source: VA SWM BMP Design Specifications)

5 Vegetated Swales

5.1 Description

A vegetated swale is a shallow, linear channel planted with a variety of vegetation to slow, filter, and infiltrate stormwater runoff. These channels are designed to filter water through the vegetation and, if sufficiently permeable, through the underlying soils. A permeable, engineered soils mix can also be included where in-situ soils are not permeable in order to provide some additional stormwater volume reduction and pollutant removal opportunities. In this instance, an underdrain or aggregate layer is also included. Vegetated swales can provide a less costly alternative to traditional curb and gutter conveyance systems and are typically used along linear, impervious features such as roads, driveways, and parking lots, or used as pre-treatment conveyance channels to other structural BMPs. Depending on the intended functionality, these systems can range from a simple channel lined with turf grass, to a more complex swale containing an engineered soil mix, underdrain, check dams, and diverse landscaping design.

Vegetated swales are known by various names, including bioswales, dry swales, wet swales, grass channels, grass swales, and biofiltration swales. These names typically vary based on design intent and are primarily influenced by soil type and extent of soil amendments, vegetation used, and period of intended ponding or saturation. Vegetated swales are typically designed as flow-through systems with little detention or storage. However, an underlying aggregate layer and/or check dams can be employed to slow flow and enhance infiltration capacity.

Figure 5-1. Vegetated swale (bioswale) in High Point, WA. (Source: American Planning Association – Washington Chapter)

Similar to bioretention facilities, a primary benefit of vegetated swales is their use in high density urban areas and along roadways where space for green infrastructure facilities is limited. Vegetated swales can also provide an aesthetically pleasing landscape feature and enhance wildlife habitat, depending on the types of vegetation used.

5.2 Feasibility Considerations

As with any LID practice, there are constraints to be considered with the use of vegetated swales. Some of the more important considerations include:

5.2.1 Contributing Drainage Area

It is generally recommended that the maximum contributing drainage area to a vegetated swale be 5 acres or less; however, larger drainage areas may be accommodated by appropriate sizing of the swale. A swale serving a drainage area of more than 10 or 20 acres may be difficult to design due to the anticipated high volume and velocity of flow. In this situation, the capacity to treat and infiltrate runoff is greatly reduced. In settings where a larger drainage area is served, check dams can be implemented to help slow flow and allow for increased infiltration. A series of inlets or diversions can also be used to convey treated water to an outlet.

5.2.2 Available Space

Vegetated swales are generally narrow, linear features that are conducive for use in high density areas, or constrained situations such as along roadways, sidewalks, utilities, parking lots, or driveways. Depending on the amount of impervious cover and other design parameters, vegetated swales should be approximately 3 to 15% of the size of the contributing drainage area.

5.2.3 Topography

Vegetated swales are generally limited to a longitudinal slope of less than 5%; however, a gradient between 1 to 2% is preferable. The slope should be as flat as possible to minimize velocities and improve filtration capacity. If slopes are greater than 2%, check dams may be required to reduce velocity. If slopes are less than 1%, ponding may occur in undesirable locations. Permeable soils and an underdrain may help in these situations. Alternatively, this practice can be combined with pocket wetland areas.

5.2.4 Available Hydraulic Head

For systems with a filter bed and/or underdrain, sufficient hydraulic head is needed to ensure free flow between the inflow point and the downstream receiving water or storm drain invert. Vegetated swales with both a filter bed and underdrain typically require 3 to 5 feet of hydraulic head.

Figure 5-2. New residential street uses a vegetated swale to capture runoff. (Source: U.S. EPA)

5.2.5 In-Situ Soils

Low permeability of soils on the site does not inhibit the use of vegetated swales, although they do determine whether soil amendments or an underdrain will be required for appropriate performance. Highly impermeable soils may require the use of both to improve infiltration capacity. Check dams may also be used to slow flows and enhance infiltration capacity.

5.2.6 Water Table

The bottom of the vegetated swale should be a minimum of 2 feet above the seasonally high groundwater table (4 ft is recommended) to ensure proper infiltration and to inhibit the potential for groundwater contamination.

5.2.7 Pollutant Hotspots

Use of vegetated swales to treat runoff from land uses with the potential for high pollutant levels should be avoided. This will help reduce the risk of hydrocarbons, trace metals, and other pollutants migrating into the groundwater.

5.2.8 Utility Conflicts

Ensure that appropriate horizontal and vertical clearance is available between utilities and swale alignment. Utilities can cross vegetated swales if they are specially protected (i.e., double casing, concrete encasement, armor rock, kevlar blanket, etc.). Owners of the utilities should be consulted to determine their requirements.

5.2.9 Location

Vegetated swales should not be located within areas that receive a baseflow or dry weather flows. Local setbacks should be determined; however, as a general rule vegetated swales should be set back at least 10 feet from building foundations, 50 feet from septic system fields, and 100 feet from water supply wells. Additionally, when used along roads, the bottom elevation of the swale should be at least one foot below the invert of the road bed.

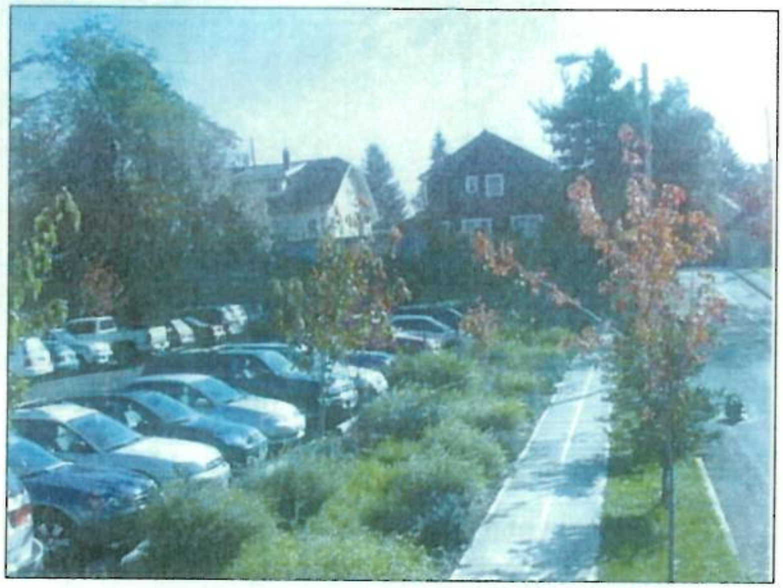

Figure 5-3. Parking lot with vegetated swale. (Source: City of Portland)

5.3 Basic Design Elements

Vegetated swales can be designed to fit a variety of site constraints, as well as to meet specific water quality/quantity requirements. Swales are typically located based on site topography and natural features and are best implemented in areas of continuous landscape. There are numerous design variations; however, there are some basic elements that each typically has in common, as summarized in the following table.

Table 5-1. Vegetated Swale Typical Design Elements

Design Element	Typical Values
Drainage Area	< 5 acres (more possible with additional design considerations)
Ponding Depth	6-12 inches (may be increased by using check dams)
Soil Matrix Composition	85-88% sand, 8-12% fines, 3-5% organic. 2-6 in/hr initial infiltration rate.
Soil Matrix Depth	18-36 inches (4-12 inches topsoil)
In-Situ Infiltration Rate	< 0.5 in/hr (without underdrain)
Choking Layer	2-4 inches sand over 2 inch layer choker stone laid above underdrain stone
Gravel Storage Layer	As necessary for underdrain or for storage, 9 - 12 in
Underdrain	6 in schedule 40 PVC with 3/8 in perforations
Geotextile Fabric	Non-woven, immediately above underdrain only
Longitudinal Slope	1% - 2% (up to 5% with check dams), unless combined with pocket wetlands in flatter systems
Side Slopes	< 3:1
Bypass/Flow Splitter	As necessary to ensure design flow is not exceeded
Vegetation	Suited to flow velocity, hydrologic regime, and soil depth
Check Dams	As necessary, use non-erosive material (i.e., riprap, wood)
Drawdown Time	Within 6-24 hours, depending on design intent

5.4 Important Construction Considerations

Following some basic construction guidelines is necessary to insure the swale performs as intended. Some of these include:

- It is imperative that vegetated swales be protected from sediment laden inflows during site construction, especially those that include a permeable soil matrix. Ideally, the swales should be built as a last step and after the contributing drainage area has been fully stabilized. Any accumulated sediment in the channel should be removed during the final stages of grading.

- Construction traffic on the swale footprint should be avoided to minimize soil compaction. This is especially important for swales that rely on the permeability of the in-situ soils. Excavation work should occur from the sides of the swale.

- It is helpful to rip or scarify the bottom of the swale to a depth of one foot to promote infiltration. Soil amendments, such as compost, can also be incorporated during this process.

- If applicable, place the soil media in 12 in lifts and flood to provide hydraulic compaction. Add additional material as necessary to ensure the proper design elevation is achieved.

- If using check dams, the top of each check dam should be constructed level at the design elevation. Check dams should be underlain with filter fabric and firmly anchored into the side-slopes to prevent scour and erosion.

- Provide irrigation of newly planted vegetation until sufficiently established.

5.5 Operation and Maintenance

Once vegetation has been established in the swale, minimal maintenance is needed to maintain proper function. Annual inspections following installation should be conducted to determine a need for maintenance such as sediment removal, re-vegetation, and stabilization. Particular items to look for include:

- Ensure that the desired coverage of turf or other vegetation has been achieved. Re-seed or vegetate any areas necessary.

- Remove any accumulated sediment. If excessive sedimentation is evident, inspect the side slopes and other features of the swale, as well as the contributing watershed, to determine the source and correct as necessary.

- Inspect check dams for evidence of undercutting or erosion; remove any trash or debris that may have accumulated.

- Check inflow and outlet points for clogging and remove any debris. Make sure there is appropriate outfall protection and/or energy dissipation at inflows.

5.6 Performance Criteria

Vegetated swales can provide effective water quality and volume reduction benefits. With the various design options regarding size, configuration, and vegetation comes differences in the anticipated removal rates. A flatter swale will allow for more infiltration, as will a swale with check dams and/or highly permeable soils (engineered or otherwise), to improve volume reduction rates. Generally speaking, a longer, continuous swale allows for maximum filtering to occur. Additionally, a swale that is planted with more dense, native plants as opposed to mowed turf grass will have a higher pollutant removal capacity. The following chart provides anticipated ranges, with steeper, less vegetated swales at the lower end and flatter, more densely vegetated swales at the higher end (note that pollutant removal represents total mass loading resulting from treatment as well as from volume reduction – Source: *VA SWM BMP Design Specifications*):

Table 5-2. Vegetated Swale Range of Typical Performance

Parameter	% Reduction	
	Turf grass with non-engineered soils	Turf/meadow grass with engineered soils
Volume Reduction (1" Storm)	10 - 20	40 - 60
Total Phosphorus (TP)	24 - 32	52 - 76
Total Nitrogen (TN)	28 - 36	55 - 74

5.7 Cost

A variety of sources and literature were reviewed to determine the average costs for vegetated swale construction and materials. These costs vary widely due to the range of project applications and design components; however, the general range is $20,000 to $30,000 per acre of impervious area treated. A simple, turf grass vegetated swale would be at the lower end of this range, while a more complex bioswale would fall at the upper end of this range. Swales requiring highly engineered soils or other more complex design considerations can cost much more.[5]

5.8 Applicability to DC Water

The use of vegetated swales is highly applicable for urban environments and is therefore an important practice for DC Water. It will take a "cultural" change to convince residents to accept such a feature in areas where they are accustomed to traditional landscape treatments. They are ideally suited for use along roadways and thus can be effective in treating these impervious surfaces. When an engineered soils mix is included, significant volume reduction can also be achieved to reduce the occurrence of CSO's and thus reduce additional runoff storage requirements.

5.9 Detailed Design References

Detailed design options are available in published documents and manuals that are periodically updated to keep abreast of advances in technology. While there are literally hundreds of such detailed design manuals, two were found to be clear and complete, and are from nearby regions:

- Virginia Department of Conservation and Recreation (DCR), Virginia Stormwater BMP Clearinghouse - http://vwrrc.vt.edu/SWC/StandardsSpecs.html.

- North Carolina Division of Water Quality, Stormwater Best Management Practices Manual - http://portal.ncdenr.org/web/wq/ws/su/bmp-manual.

It is important to make certain the selected design options are acceptable to the District Department of the Environment (DDOE) prior to implementation and are in accordance with DDOE design

[5] Cost Estimate Sources: DC Department of the Environment Riversmart Program, Water Environment Research Foundation, U.S. EPA, Maryland Department of the Environment, Southeast Michigan Council of Governments

guidance. DDOE is currently in the process of revising current guidance and adopting the runoff reduction methodology used by the Virginia Department of Conservation and Recreation (as communicated in an email from Rebecca Stack, DDOE, 3/19/12).

5.10 Example Applications

The following provide some typical schematics and photos of vegetated swales in confined, urban settings that are applicable to DC Water:

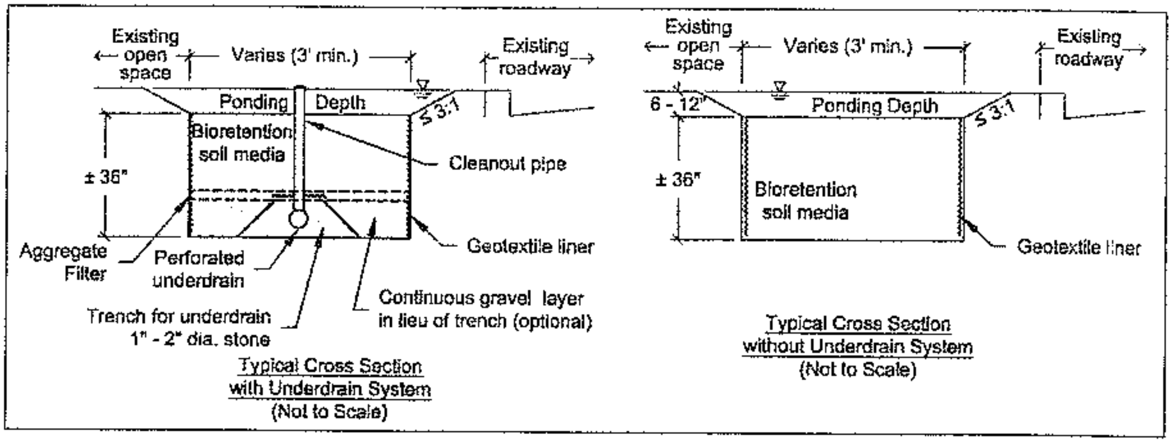

Figure 5-4. Schematic of typical vegetated swale with and without underdrain system. (Source: Wetland Studies and Solutions, Inc.)

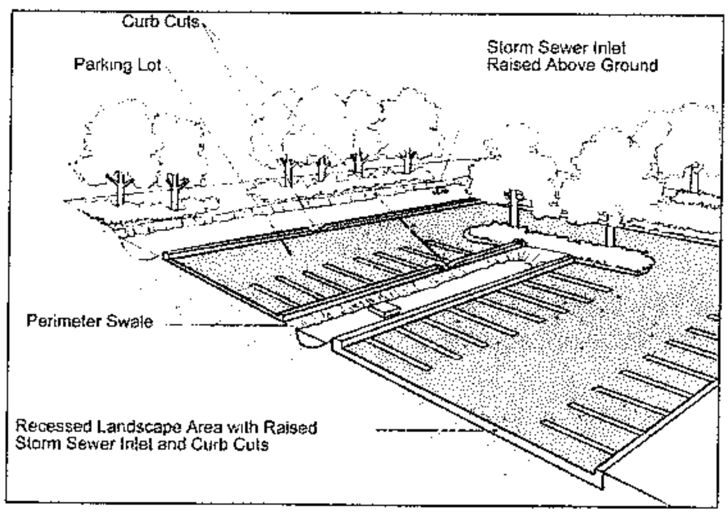

Figure 5-5. Schematic of a typical parking lot swale drainage. (Source: Northern Illinois Planning Commission)

Figure 5-6. Typical parking lot vegetated swale. (Source: Southeast Michigan Council of Governments)

Figure 5-7. Wet swale and controlled canal in Champaign, IL. (Source: University of Illinois, Department of Urban and Regional Planning)

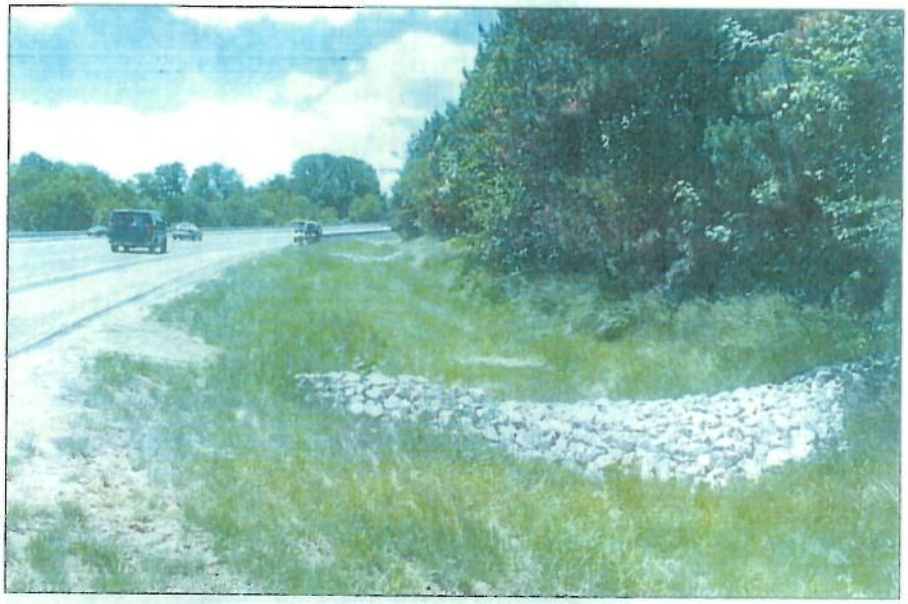

Figure 5-8. Vegetated swale with check dams.
(Source: Delaware Department of Transportation)

Figure 5-9. Residential vegetated swale, Seattle, WA.
(Source: Seattle Public Utilities)

6 Green Roofs

6.1 Description

Green roofs, also known as vegetated roofs, living roofs, or ecoroofs, are vegetated roof surfaces underlain with a permeable soil layer, drainage matrix, and waterproof base layer that protects the roof's structural surface from moisture. Roof tops typically generate one of the highest sources of stormwater runoff in urban areas. Green roofs can be used to reduce stormwater volume through retention and detention, reduce peak runoff rates, improve water quality, provide wildlife habitat, and mitigate the urban heat island effect. Research also shows that green roofs provide an economic benefit by conserving energy and providing a longer lifespan than traditional roofs (as green roofs are protected from UV radiation and extreme changes in temperature).

Green roofs systems are generally separated into two types: extensive and intensive, which are differentiated primarily on the depth of the growing media, vegetation types, and planned usage. Extensive systems have a relatively shallow growing media (4 to 8 inches), which is planted with a variety of hardy, drought tolerant vegetation. Extensive systems are much lighter and economically feasible than intensive systems. Intensive systems contain a deeper growing media (up to 4 feet), which can be planted with a wide range of trees, shrubs, and herbaceous vegetation. These systems generally involve more landscape maintenance and irrigation. Intensive systems are not as widely used and are often difficult to implement in retrofit situations.

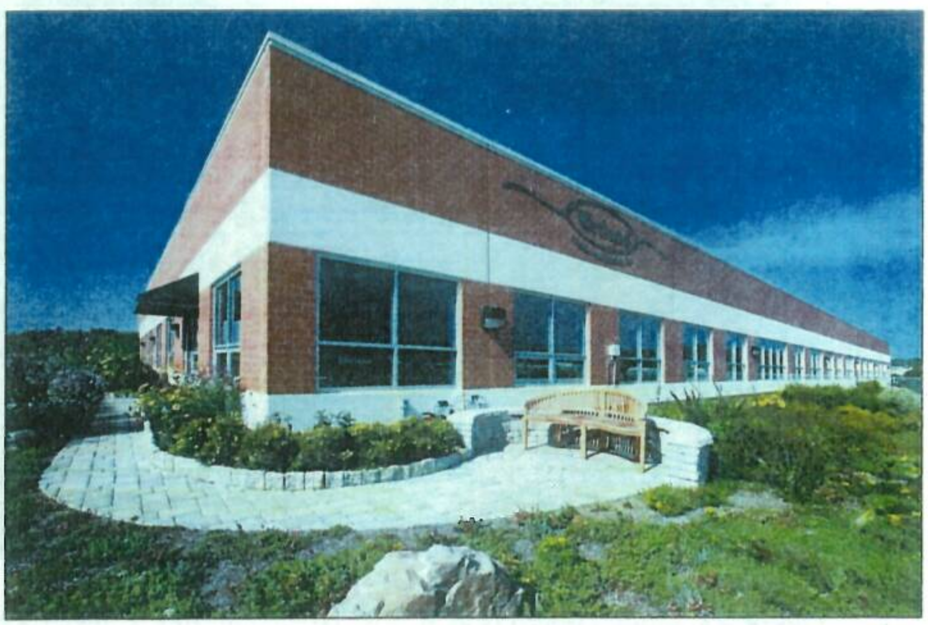

Figure 6-1. Green roof at Wetland Studies and Solutions, Inc. office, Gainesville, VA (Source: Wetland Studies and Solutions, Inc.)

6.2 Feasibility Considerations

Perhaps more than any other LID practice, there are significant limitations on the use of green roofs that must be considered. Some of the more important include:

6.2.1 Structural Capacity of the Roof

The most significant consideration when assessing the feasibility of a green roof is the required structural capacity of the roof, which must not only support the additional stormwater, but also the weight of the soil, biomass, and other structural components of the roof. Extensive green roofs require 15 to 30 lbs per square foot, while intensive green roofs require 35 to 100 lbs per square foot. A structural engineer or architect should be involved with the roof assessment to determine whether the building's structural capacity is sufficient.

6.2.2 Roof Slope

The benefits of stormwater treatment and retention are maximized on a relatively flat roof (approximately 1 to 2%); however, with appropriate design, a green roof can be installed on roofs with slopes of up to 45%. Technical precautions, such as baffles, grids, or strips should be used to prevent slippage and erosion on slopes over 17%.

Figure 6-2. Sloped green roof at 5404 Wisconsin Ave, Chevy Chase, MD. (Source: Capitol Greenworks)

6.2.3 Roof Access

Green roofs do require occasional maintenance and inspection, so appropriate access to perform these tasks (as well as deliver construction materials) should be factored into the feasibility assessment and design. Access can typically be achieved by an interior stairway with roof hatch or trapdoor with minimum dimensions of 16 square feet in area.

6.2.4 Roof Type

Green roofs can be installed on a variety of roof types. Typically, concrete, wood, or metal sheeting is a preferred substructure. Exposed treated wood, uncoated galvanized steel, or other surfaces containing pollutants are not recommended due to the risk of those toxins leaching through the soil media to the plants.

6.2.5 Setbacks

Care should be taken when siting a green roof in the vicinity of rooftop electric and HVAC systems. Appropriate firebreaks should be installed around these systems, as well as other roof penetrations or openings (i.e., skylights). A 2-foot wide vegetation-free zone (i.e., gravel strip or concrete slab) is recommended around the perimeter of the roof and a 1-foot wide vegetation-free zone should be maintained around all roof penetrations/openings. On larger roof tops, it is recommended that vegetation-free zones be installed every 130 feet to provide access ways.

6.2.6 Irrigation

An extensive green roof is generally planted with drought-tolerant, hardy species and will only require irrigation during planting and maintenance over the first 2 years. After the roof is established, annual rainfall should be sufficient to maintain to vegetation. Irrigation requirements for an intensive green roof are more involved, as this vegetation will consist of larger trees, shrubs, and herbaceous species. If considering an intensive green roof, an adequate number of irrigation units and appropriate water supply may need to be accounted for.

6.2.7 Local Building Codes

Local planning and zoning authorities should be consulted to ensure that the green roof complies with all local building codes and that the necessary permits are obtained. Design components, such as roof drains and overflow devices, may have specific requirements.

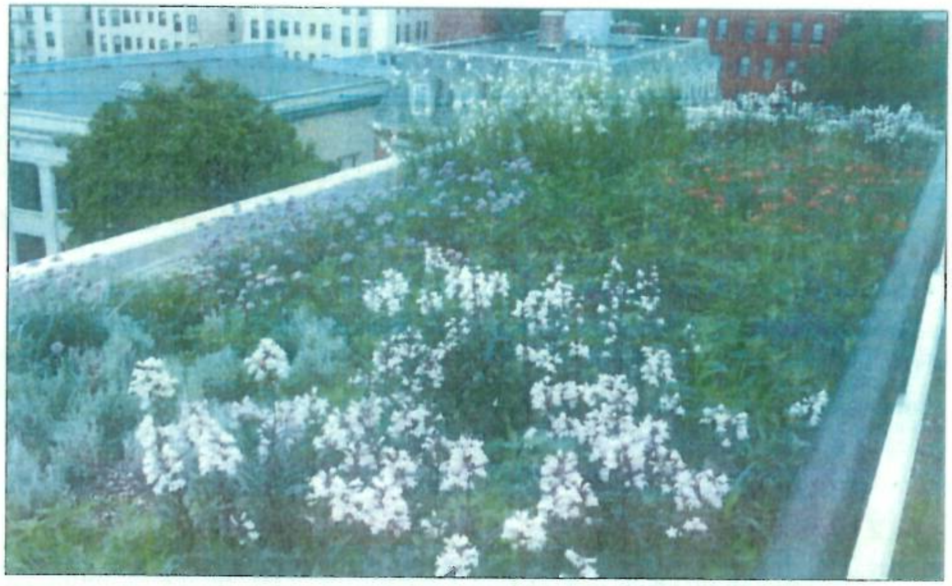

Figure 6-3. Franklin D. Reeves Center green roof in Washington D.C. (Source: dc greenworks)

6.3 Basic Design Elements

Green roofs can be designed for a variety of settings, including commercial, residential, and industrial facilities. Specific volume reduction, peak rate mitigation, and water quality improvements are determined by the basic design elements. These elements vary by project; however, some of the basic elements that each project typically has in common are summarized in the following table.

Table 6-1. Green Roof Typical Design Elements

Design Element	Typical Values
Structural Roof Capacity	15 – 30 lbs/square foot (extensive); 35 – 100 lbs/square foot (intensive)
Roof Slope	0 – 25% (treatment is maximized on flat roofs)
Deck Layer	Concrete, wood, metal, plastic, gypsum, composite
Waterproofing Layer	100% waterproof – methods vary
Insulation Layer	Methods vary – installed above or below waterproofing layer
Root Barrier	Methods vary – do not use pesticides, metals, or other chemicals
Drainage Layer	1 – 2 inches washed granular material (gravel, recycled polyethylene, etc.)
Root Permeable Filter Fabric	Needled, non-woven, polypropylene geotextile
Growing Media (extensive)	4 – 8 inches deep
Growing Media (intensive)	8 inches - 4 feet deep
Growing Media Composition	80 – 90% lightweight inorganic, 20% organic (well-aged compost)
Water Retention Capacity	< 30%
Vegetation (extensive)	Mostly non-native, slow-growing, shallow-rooted, perennial, hardy plants
Vegetation (intensive)	Fewer limitations – herbs, forbs, grasses, shrubs, trees

6.4 Important Construction Considerations

There are important construction guidelines that must be followed to ensure success of a green roof project. Given the diversity of green roof designs and applications, construction will be slightly different in each situation. However, following are some general construction considerations:

- The roof deck should be constructed with the appropriate slope and material. If constructing a retrofit project, conduct the appropriate testing to ensure that the structural capacity is adequate to support the additional loading associated with the green roof.

- A waterproof membrane is a vital component of a green roof and protects the roof deck material from moisture and root damage. During construction, ensure that the waterproof membrane is thoroughly checked for gouges, tears, or stretching and is tested for leaks prior to placement of overlying materials. Many waterproofing layers are also root resistant; however, if using a membrane that is not root resistant, an additional root barrier has to be installed.

- After the waterproof membrane is installed, a flood test should be conducted to ensure that that they system is water tight and functional. It is generally recommended to place at least 2 inches of water over the membrane for a period of 48 hours to test the integrity of the waterproof barrier.

- Roof drains or outlets should be installed throughout the green roof to drain surplus water accumulation as necessary. The number and location of roof outlets will vary depending on the design and size of the project. Outlets should be kept free of debris and vegetation at all times. Inspection chambers may be installed over roof outlets to aid in inspection.

- A lightweight growing media, containing no more than 20% organic content, should be mixed prior to installation and then spread evenly over the filter fabric layer below. The timing of planting depends on the local climate and season; however, if planting will not occur immediately, the growing media should be covered to prevent the growth of weeds. Care should also be taken to limit foot and construction traffic over the growing media to reduce compaction.

- Vegetation considerations vary depending on extensive or intensive green roof design. Extensive green roofs generally include plants that can withstand harsh solar radiation, wind exposure, extreme temperature fluctuations, and limited root growth. Therefore, varieties such as sedum and low growing grasses and wildflowers are typically used. Irrigation is only necessary until the extensive green roof becomes established. Vegetation on intensive green roof systems can be more diverse, due to a deeper growing medium that supplies more consistent nutrients and water. Native vegetation can be used more readily, including varieties of perennials, herbs, grasses, trees, and shrubs. Long term irrigation measures need to be incorporated into intensive green roof construction. Subsurface or drip irrigation methods are preferred.

Figure 6-4. Placement of growing media at Wetland Studies and Solutions, Inc. (Source: Wetland Studies and Solutions, Inc.)

6.5 Operation and Maintenance

Because green roofs are comprised of several important layers and components, proper operation, maintenance, and inspections are necessary to maintain a functioning system. Inspections during construction and at least twice a year during the growing season following construction are of particular importance. Items to look for include:

- Vegetation requires routine inspection and maintenance to ensure that dead and dying plants are removed and invasive species are weeded out. Replace/replant as necessary to repair bare areas. Slow release fertilizer is also recommended annually for the first five years after the green roof is installed (this is not recommended if the green roof is being used for water quality improvement). The use of herbicides, pesticides, and fungicides is discouraged due to potential harm they could cause the waterproof membrane.

- Ensure that adequate irrigation is provided immediately after planting and until the green roof vegetation has fully established. In situations where an irrigation system cannot be installed, hand watering may be necessary. Intensive green roof systems typically require a permanent irrigation system and regular water application. Inspect automatic controls, such as the rain shutoff sensor, on permanent irrigation systems.

- Inspect the waterproof membrane for leaks. If a leak is suspected, flood testing and/or an electric leak survey (i.e. electric field vector mapping) can be used to pinpoint the exact location of the leak and to facilitate making localized repairs.

- Inspect roof drains, spouts, gutters and other components of the roof drainage system for clogs. Remove any debris or foreign material immediately to ensure proper drainage.

6.6 Performance Criteria

Green roofs can provide effective water quality and volume reduction benefits. With the various design options regarding roof size, growth media, and vegetation comes differences in the anticipated removal rates. Note that typically, pollutant removal is provided through a reduction in runoff volume, not through treatment processes. The following chart provides anticipated ranges for **extensive** green roofs, which are more commonly used for development and redevelopment sites (note that pollutant removal represents total mass loading resulting from volume reduction only as no removal from treatment is credited – Source: *VA SWM BMP Design Specifications*):

Table 6-2. Green Roof Range of Typical Performance

Parameter	% Reduction
Volume Reduction (1" Storm)	45 - 60
Total Phosphorus (TP)	45 - 60
Total Nitrogen (TN)	45 - 60

6.7 Cost

A variety of sources and literature were reviewed to determine the average cost for green roof construction and materials. These costs vary widely depending on the application; however, a general range is between \$6 and \$90 per square foot of impervious area treated. Within this range, extensive green roof systems typically cost between \$8 and \$20 per square foot and intensive green roofs generally run between \$15 and \$50 per square foot.[6]

6.8 Applicability to DC Water

With rooftops representing a significant portion of the impervious area in urban settings, application of green roofs can potentially provide a benefit in terms of runoff reduction. However, there are structural requirements that must be met, which is not always possible in retrofit situations. In addition, buildings that are privately owned will require approval, which may not be easily obtained.

[6] Cost Estimate Sources: DC Department of the Environment Riversmart Program, Water Environment Research Foundation, U.S. EPA, Low Impact Development Center, Center for Clean Air Policy, Southeast Michigan Council of Governments, New York City Department of Environmental Protection, City of Seattle, Great Lakes Water Institute

6.9 Detailed Design References

Detailed design options are available in published documents and manuals that are periodically updated to keep abreast of advances in technology. While there are literally hundreds of such detailed design manuals, two were found to be clear and complete, and are from nearby regions:

- Virginia Department of Conservation and Recreation (DCR), Virginia Stormwater BMP Clearinghouse - http://vwrrc.vt.edu/SWC/StandardsSpecs.html.

- North Carolina Division of Water Quality, Stormwater Best Management Practices Manual - http://portal.ncdenr.org/web/wq/ws/su/bmp-manual.

It is important to make certain the selected design options are acceptable to the District Department of the Environment (DDOE) prior to implementation and are in accordance with DDOE design guidance. DDOE is currently in the process of revising current guidance and adopting the runoff reduction methodology used by the Virginia Department of Conservation and Recreation (as communicated in an email from Rebecca Stack, DDOE, 3/19/12).

6.10 Example Applications

The following provide some typical schematics and photos of green roof applications:

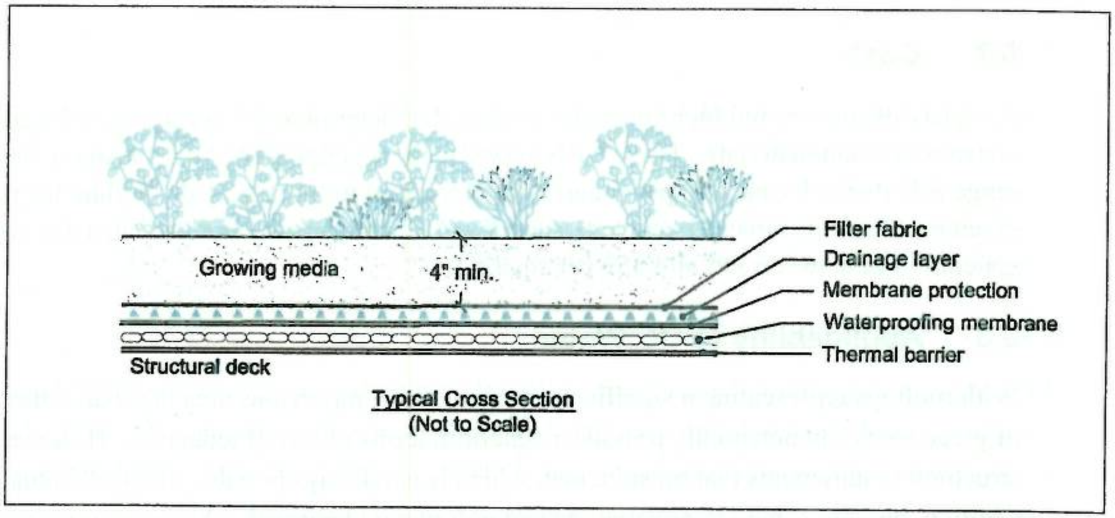

Figure 6-5. Green roof with membrane liner system – typical cross section. (Source: Wetland Studies and Solutions, Inc.)

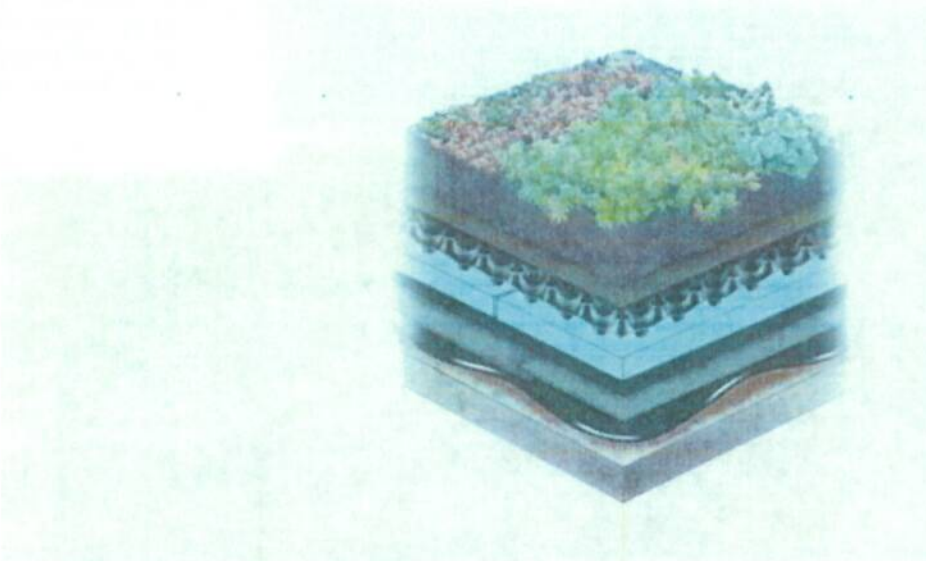

Figure 6-6. Example profiles for extensive (left) and intensive (right) green roof systems.
(Source: American Hydrotech, Inc.)

Figure 6-7. Cannon House Office Building green roof demonstration project, Washington, DC.
(Source: Capitol Greenroofs)

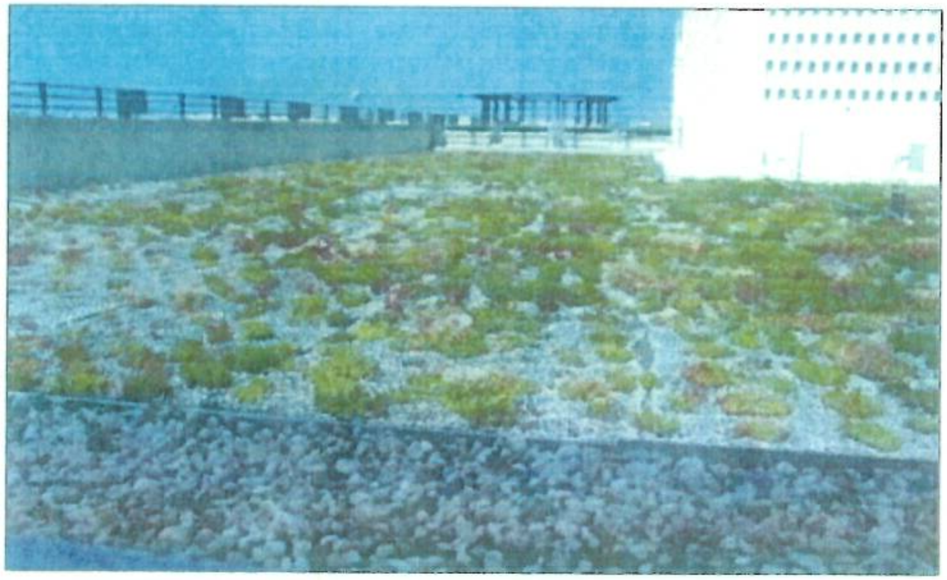

Figure 6-8. Green roof on a commercial building at 1425 K Street NW, Washington, DC. (Source: dc greenworks)

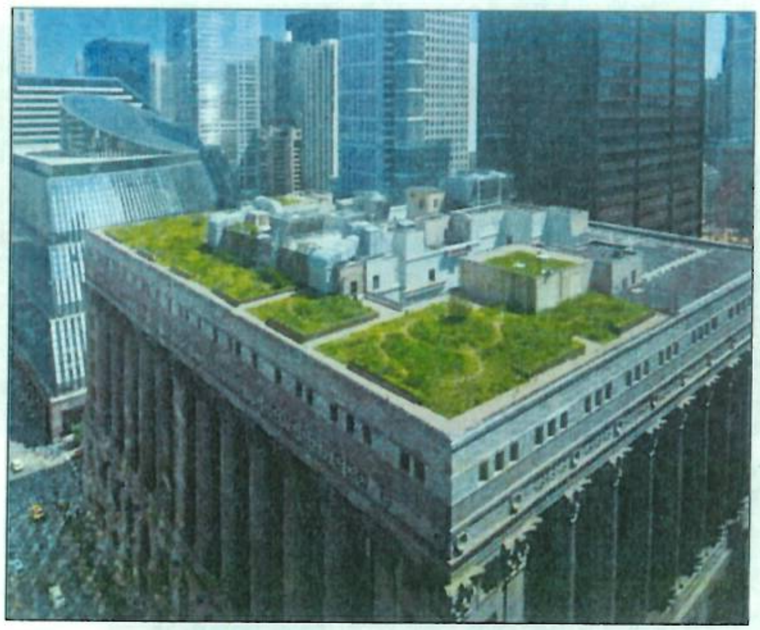

Figure 6-9. Green roof on City Hall, Chicago, IL. (Source: City of Chicago)

Figure 6-10. Green roof at Ohio EPA building, Columbus, OH. (Source: The Ohio State University)

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7 Rainwater Harvesting

7.1 Description

The practice of rainwater harvesting includes the storage of stormwater for later reuse on the site. The types of suitable uses can include such non-potable demands as landscape irrigation, use in toilets and urinals, use in cooling towers, exterior washing applications, supply for replenishing water fountains or other features, or sprinkler systems. Use of stormwater for these purposes can reduce the volume of runoff from the site and reduces the demand from potable sources.

While the specific design and type of rainwater harvesting systems can vary significantly, there are basic components that most have in common (more specifics are provided in Section 7.3:

- Rooftop
- Collection/conveyance system
- Screen and first-flush diverter
- Cistern/storage system
- Distribution system
- Overflow system

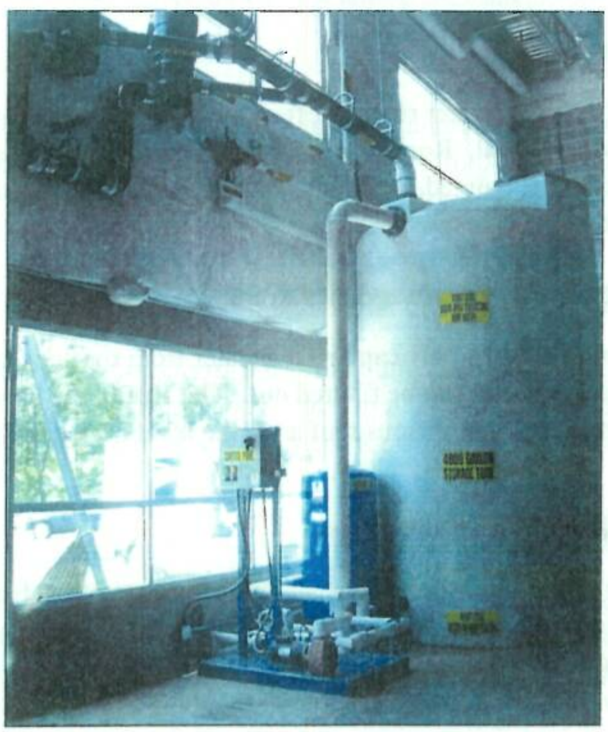

Figure 7-1. Cistern for toilet use at Wetland Studies and Solutions, Inc. (Source: Wetland Studies and Solutions, Inc.)

Rainwater can be stored in tanks or cisterns made of fiberglass, concrete, plastic, brick, or other materials. They can be located above or below ground and can be sized to contain various volumes to meet the desired goals of the project.

The practice of harvesting rainwater is ideally suited for urban situations – while space is limited, this practice can be designed to fit in the urban landscape and many of the re-use applications are suitable for high density, urban environments where higher water demands exist. An important consideration, however, is that certain re-uses require and are subject to review and approval from the local regulatory authority.

7.2 Feasibility Considerations

While suited for use in urban areas, there are constraints that must be considered to determine the feasibility of employing rainwater harvesting techniques:

7.2.1 Location

Rainwater harvesting cisterns and/or other storage vessels can be easily integrated into development sites, especially when accounted for in the design process. Even as retrofits, cisterns can be placed within or on buildings (assuming sufficient structural support is available), outside adjacent to buildings, or underground. They can also be designed creatively to enhance the aesthetics of a building.

7.2.2 Rooftop Material

The quality of water running off of the roof will be determined in large part by the type of roofing material. Roofs made from materials that may add pollutants to the runoff, such as tar and chip, painted roofs, galvanized metal roofs, asphalt seal coated roofs, etc, should be avoided.

7.2.3 Contributing Drainage Area

It is preferable to only capture rainwater from rooftops to limit the amount of pollutants and debris that must then be filtered out. The size of the cistern or other tank will be dictated by the amount of impervious roof area, the level of demand, and available space.

7.2.4 Available Hydraulic Head

The hydraulics of the system and intended uses of the harvested water play an important role in siting and design. There are losses associated with the collection and movement of water through inlets and pipes that will determine pumping requirements. While locating the cistern in a low spot in the site will facilitate gravity flow of water into the tank, it will increase pumping requirements to distribute the collected water to the point of use. Thus, it is important to make sure the desired goals of the rainwater harvesting system can be achieved before implementation.

7.2.5 Available Space

As discussed above, placement of storage vessels for the collection of rainwater can be tailored to fit the available space.

Figure 7-2. Cistern located in a stairwell.
(Source: Nevue Ngan Associates)

7.2.6 Topography

Site topography does not impact the potential for using rainwater harvesting techniques, provided a level foundation can be provided. It should be considered, however, as it relates to the necessary hydraulic head requirements discussed above.

7.2.7 In-Situ Soils

Soils can play a role in the design of the system in regards to the structural support of the tank. In addition, soil pH should be considered as it may impact the selection of the cistern material in underground applications.

7.2.8 Water Table

For underground tanks, it is preferable to place it in locations above the water table. If this is not possible, buoyancy and the potential for inflow must be considered.

7.2.9 Utility Conflicts

Any required excavation for the installation of the cistern and/or the associated piping must consider the possibility of utility conflicts.

7.2.10 Set-Backs

Care should be taken to minimize a hydraulic connection to adjacent buildings without proper waterproofing protection. This may be relevant for cistern overflow devices.

7.2.11 Hot-Spot Land Uses

The use of cisterns may be helpful in preventing rooftop runoff from flowing through contaminated areas on the site.

7.3 Basic Design Elements

Each of the basic components of a rainwater harvesting system has design elements to consider, as described below:

7.3.1 Rooftop

An ideal rooftop will be made of a smooth, non-porous material that readily drains to the outlet point. The type of roof material should be considered in determining the intended use of the harvested water – potentially polluting materials may require expensive treatment of the harvested water prior to use.

7.3.2 Collection/Conveyance System

The conveyance system includes gutters and downspouts, as well as any associated piping necessary to route the captured runoff to cisterns. Aluminum downspouts and gutters are typically recommended in sloped roof systems and must be able to accommodate the desired storm event. In flat roof systems, ductile iron or PVC, depending on code requirements are typically used.

7.3.3 Screen and First-Flush Diverter

Prior to entering the cistern, runoff must pass through a screen or filter to remove any debris, such as leaves, twigs, sediment, insects, etc. that may have collected on the rooftop. These screens and filters should be low maintenance or maintenance free devices. First-flush diverters are suggested and intended to allow a very small amount of the beginning of the rain event (up to 0.06") to bypass the system, thereby keeping pollen, dust, or other collected materials from entering the cistern. However, systems have been known to operate without such diverters.

7.3.4 Cistern/Storage System

The storage tank can be made of a variety of materials that, depending on the location, should adhere to certain criteria. Those located aboveground should be UV and impact resistant and either be opaque or located out of direct sunlight to inhibit algal growth. Tanks located below ground must be capable of supporting soil and/or vehicular loads as necessary. All components of the system should be sealed with nontoxic and waterproof materials. Tanks should have an opening to allow entry for maintenance and inspection, and this access point must be kept sealed to prevent unauthorized access.

Figure 7-3. Multiple underground cisterns in series.
(Source: VA SWM BMP Design Specifications)

7.3.5 Distribution System

Depending on the end use, most distribution systems will require a pump. Distribution lines should be installed below the frost line.

7.3.6 Overflow System

Cisterns or other water storage tanks must be equipped with an overflow mechanism that allows for the release of water from storm events that exceed the capacity of the tank. While a pumped system may be required, gravity flow is preferred. Overflow paths should be to stable outlets that take into consideration the location of buildings or other areas where occasional flow would not be desirable.

7.4 Important Construction Considerations

Rainwater harvesting systems should be installed by a qualified, experienced contractor. A licensed plumber is required to connect the system components to the plumbing system.

7.5 Operation and Maintenance

The level of required maintenance is dependent upon the use – systems that simply provide supplemental irrigation do not require as much maintenance as systems that supply water for indoor uses. Recommended maintenance items include the following:

- Keep gutters and downspouts free of debris.
- Inspect and clean pre-screening devices and first flush diverters.
- Inspect and clean the tank and other system components.
- Inspect the structural integrity of the tank, pump, pipes, and electrical system.
- Inspect the overflow area to ensure it remains stable.

7.6 Performance Criteria

The volume reduction depicted in the following table assumes that there is sufficient demand to utilize the entire volume from the design storm and that no overflow will occur. Simulations using historic rainfall data and use estimates are necessary to select the appropriate design storm and to appropriately size the cistern. Note that pollutant removal is determined on a mass load basis by the amount of runoff that is prevented from being released. No reduction based on treatment is credited (Source: *VA SWM BMP Design Specifications*):

Table 7-1. Rainwater Harvesting Range of Typical Performance

Parameter	% Reduction
Volume Reduction	90
Total Phosphorus (TP)	90
Total Nitrogen (TN)	90

The 90% reduction (vs. 100%) is a gross estimate to account for first flush diverters (≤ 0.06 inches).

7.7 Cost

A variety of sources and literature were reviewed to determine the average costs for rainwater harvesting systems construction and materials. The costs vary widely due to the range of project applications and installation components. Generally, these costs range from $0.50 to $30 per gallon of rainwater stored. While applications such as rain barrels typically cost $2 to $4 per gallon stored, a cistern will ranged between $0.50 and $4 per gallon stored. Additional components for water reuse, such as irrigation or facility toilets/gray water, will add to the cost. These types of projects can range from $20 to $30 per gallon stored – especially if they are retrofit projects.[7]

7.8 Applicability to DC Water

Rainwater harvesting is directly applicable for use by DC Water. It is well suited to urban environments and can be tailored to fit the available space (although retrofits inside existing buildings can be problematic). In addition, urban settings with high density uses can create sufficient demand to provide a use for the collected runoff. This not only reduces demand from potable sources, but can also effectively reduce the runoff from the site – reducing required storage for CSO events.

7.9 Detailed Design References

Detailed design options are available in published documents and manuals that are periodically updated to keep abreast of advances in technology. While there are literally hundreds of such detailed design manuals, the following are particularly clear and complete, and are from a nearby region:

- Virginia Department of Conservation and Recreation (DCR), Virginia Stormwater BMP Clearinghouse - http://vwrrc.vt.edu/SWC/StandardsSpecs.html.

- Virginia Rainwater Harvesting & Use Guidelines developed by the Virginia Department of Health - http://www.vdh.virginia.gov/EnvironmentalHealth/ONSITE/technicalresources/documents/2011/pdfs/VDH%20Rainwater%20Use%20Guidelines%20V2011_03.pdf

It is important to make certain the selected design options are acceptable to the District Department of the Environment (DDOE) prior to implementation and are in accordance with DDOE design guidance. DDOE is currently in the process of revising current guidance and adopting the runoff reduction methodology used by the Virginia Department of Conservation and Recreation (as communicated in an email from Rebecca Stack, DDOE, 3/19/12).

There is another consideration that could require a waiver from DDOE as it relates to the requirements contained in the 2009 Uniform Statewide Building Code. There is a restriction contained within the Code that limits the storage of rainwater for irrigation purposes to a duration of 24 hrs and the storage of rainwater for use within buildings to a duration of 72 hours. Again, localities can issue waivers to these restrictions in many instances.

7.10 Example Applications

The following are some examples of cistern applications:

[7] Cost Estimate Sources: DC Department of the Environment Riversmart Program, Water Environment Research Foundation, U.S. EPA, Southeast Michigan Council of Governments, Monterey County, Sustainable Cities Institute, Green Affordable Housing Commission

Figure 7-4. Multiple underground cisterns in series.
(Source: LID Manual for Michigan)

Figure 7-6. Aesthetically pleasing metal cistern.
(Source: Nevue Ngan Associates)

Figure 7-7. Irrigation cistern at Wetland Studies and Solutions, Inc. (overflow to rain garden). (Source: Wetland Studies and Solutions, Inc.)

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8 Blue Roofs

8.1 Description

Blue roofs are a form of rooftop detention in which rainfall is collected, temporarily stored, and gradually released through a controlled-flow system off a building's roof. Water is ponded for a short period of time, typically in a series of trays or cells (often filled with gravel ballast), to help reduce peak runoff volume (and potentially total volume in warm weather) and discharge frequencies. Runoff from a blue roof is controlled by weirs or orifices that are attached to roof drains to slow flow into the facility's storm drains or roof leaders or to be stored for beneficial reuse. Temporary water storage on a blue roof provides an added benefit of temperature regulation through evaporative cooling in warmer months. Along with light colored building materials, the implementation of blue roofs can help reduce the urban heat island effect.

Blue roofs provide many of the same stormwater benefits of a green roof (although green roofs provide additional environmental benefits such as wildlife habitat), but cost considerably less. Blue roofs are an ideal green infrastructure candidate in urban areas where rooftops comprise the majority of impervious surface at a given site. Installation and maintenance of a blue roof is relatively easy and does not require much more work than a standard roof, although there are some structural requirements that must be taken into account. Installation of a blue roof is expected to extend the life of the roof membrane due to a reduction in temperature swings resulting from evaporative cooling and reduced sunlight exposure.

Figure 8-1. Blue roof trays, New York, NY. (Source: New York City Housing Authority)

8.2 Feasibility Considerations

To a lesser extent than with green roofs, use of blue roofs does require careful consideration of the structural capacity of the roof, along with other considerations as discussed below:

8.2.1 Structural Capacity of the Roof

The required structural capacity of the roof depends primarily on how much water is to be detained by the blue roof system. Generally, a blue roof is designed to detain up to 3-4 inches of rainfall, which would add 15 to 20 lbs per square foot (one inch of ponded stormwater on a rooftop adds approximately 5 lbs per square foot of loading). If loading capacity is limited, the detention volume can be reduced. These requirements are typically less than that of a green roof, which requires additional capacity for soil media and vegetation. A structural engineer or architect should be involved with the roof assessment to determine whether the building's structural capacity is sufficient.

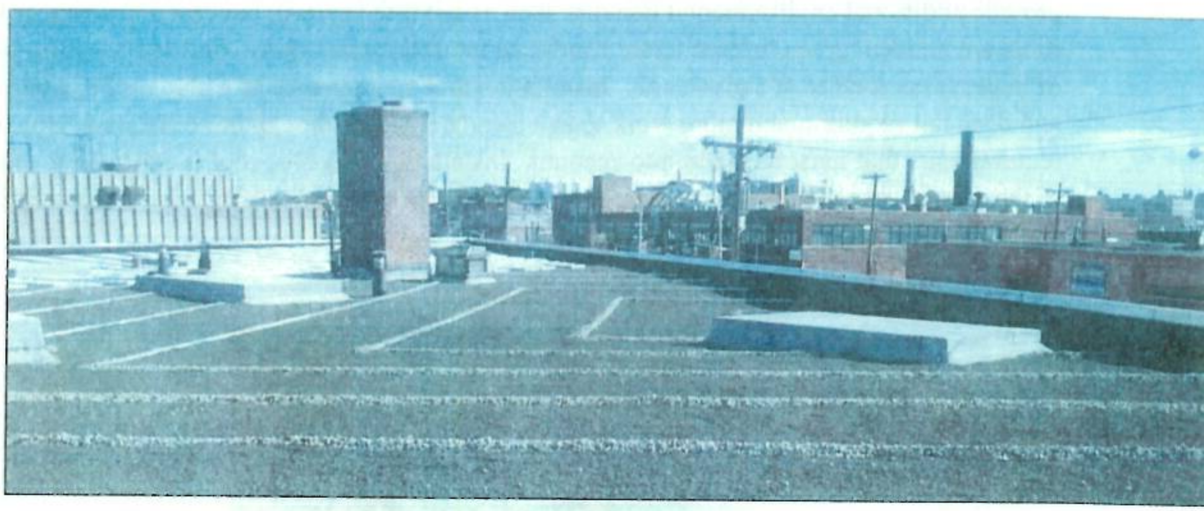

Figure 8-2. Check dams installed to control flow on sloped portion of roof, Brooklyn, NY. (Source: New York City Department of Environmental Protection)

8.2.2 Roof Slope

Blue roofs are typically implemented on roofs with a relatively flat slope (less than 2%). Maximum storage volume is available on roofs with slopes between one half and 2%. Special modifications, such as check dams, that help mitigate slope and evenly distribute ponded water are required on slopes greater than 2%.

8.2.3 Roof Access

Blue roofs require occasional maintenance and inspection, so appropriate roof access is required to perform these tasks. Blue roof systems typically consist of modular storage trays or cells and adequate access must be available to transport these materials to the rooftop and replace if necessary. Because of their modular nature, blue roof systems can often complement other rooftop usage, such as urban agriculture, decking, solar panels, rainwater recycling, and mechanical equipment.

8.2.4 Roof Type

Blue roofs can be installed on a wide variety of roof types. Metal roof panels are not typically recommended for blue roofs due to their required slope (generally a minimum of 2%).

8.2.5 Roof Drains

Roof drains and scuppers should be sized and installed appropriately for the blue roof's designated design. Additionally, roof drains should be located away from trees if possible to prevent clogging from leaf litter.

8.2.6 Local Building Codes

Consult with local planning and zoning authorities to ensure that the blue roof complies with all local building codes and that the necessary permits are obtained. Design components such as roof drains and overflow devices may have specific requirements.

8.3 Basic Design Elements

Blue roofs can be designed to fit a variety of settings, especially in high density, urban areas where space is constrained and rooftops are contributing significantly to stormwater runoff. Specific detention amounts, peak rate mitigation, and volume reduction are determined by the basic design elements. While these designs vary from project to project, some of the basic elements are outlined in the following table.

Table 8-1. Blue Roof Typical Design Elements

Design Element	Typical Values
Structural Roof Capacity	15 – 20 lbs/sf
Roof Slope	< 2%
Ponding Depth	2 – 4 inches typical, but variation is easy to achieve
Deck Layer	Variable
Waterproofing Layer	100% waterproof – methods vary
Insulation Layer	Methods vary – installed above or below waterproofing layer
Ballast Layer	Optional, depending on design. Depth and material vary (typically washed gravel)
Roof Drains	Min. 2 drains for < 10,000 sf of area; min. 4 drains for >10,000 sf of area
Drawdown Time	Maximum 24 hours, typically

8.4 Important Construction Considerations

There are important construction guidelines that must be followed to ensure success of the blue roof project. Given the diversity of blue roof designs and applications, construction will be slightly different in each situation. However, following are some general construction considerations:

- The roof deck should be constructed of with the appropriate slope and material. If implementing a retrofit project, conduct the appropriate analysis to ensure that the structural capacity is adequate to support the additional loading associated with the blue roof. Many localities require that traditional roof designs be based on a load of 30 lbs per square foot. Therefore, properly designed traditional roofs are typically structurally capable of holding detained stormwater loads associated with a blue roof system.

- A waterproof membrane is a vital component of a blue roof and protects the roof deck material from moisture. During construction, ensure that the waterproof membrane is thoroughly checked for gouges, tears, or stretching prior to placement of overlying materials.

- After the waterproof membrane is installed, a flood test should be conducted to ensure that that they system is water tight and functional. It is generally recommended to place at least 2 inches of water over the membrane for a period of 48 hours to test the integrity of the waterproof barrier.

- Roof drains and leaders should be sized and installed throughout the blue roof system in accordance with the design. Roof drains and volumetric weirs appropriate for use on a blue roof are available both commercially and customized through various manufacturers. At a minimum, two roof drains should be installed for a roof area of less than 10,000 square feet and four roof drains should be installed for a roof area of greater than 10,000 square feet. Roof areas exceeding 40,000 square feet should have at least one drain for every 10,000 square feet. Controlled flow roof drains are sized to appropriately convey the desired volume and flow from the roof during a storm. Ensure that weir controlled roof drains are tamper proof to prevent unauthorized or unintentional modifications. Additionally, strainers should be installed around drain inlets to prevent clogging from leaf litter and other debris.

Figure 8-3. Strainers or screens help prevent debris from clogging roof drains. (Source: New York City Department of Environmental Protection)

- All blue roofs installations should include emergency overflow roof drains or scuppers, which should be located at the desired ponding depth based on the structural capacity analysis.

8.5 Operation and Maintenance

Blue roofs should be monitored closely during the first year after installation to ensure that the system is effective and determine whether any modifications are necessary. It is recommended that blue roofs be inspected semi-annually under dry conditions and as needed after rain events. After the first year of monitoring and maintenance, these frequencies can be modified for site specific conditions. Particular items to look for include:

- Inspect roof drains, spouts, gutters and other components of the roof drainage system for clogs. Remove any debris or foreign material immediately to ensure proper drainage. Additionally, check roof drains after snow and/or ice events to ensure that blockage has not occurred due to a build-up.

- Inspect the waterproof membrane for leaks. If a leak is suspected, flood testing and/or an electric leak survey (i.e. electric field vector mapping) can be used to pinpoint the exact location of the leak and to facilitate making localized repairs. Because most blue roofs are comprised of modular systems that can be moved as necessary, repair and maintenance of the waterproof layer can be performed with ease.

- Blue roofs should be inspected within 24 hours after significant rain events to ensure that the specified ponding depths and drainage times are being achieved. This will also verify that standing water does not persist for more than 24 hours.

8.6 Performance Criteria

Blue roofs primarily provide a benefit through detention and reduction of peak discharge frequencies. At a minimum, blue roofs should be designed to reduce the peak flow of the rooftop runoff to meet local stormwater goals. It may be desirable to design for larger, less frequent storms. Additionally, minor reductions in stormwater volume may be seen through evaporation. More significant volume reductions may be seen if the blue roof is combined with a secondary BMP such as an infiltration trench, rain garden, green roof, or alternative method to reuse/recycle the water.

8.7 Cost

A variety of sources and literature were reviewed to determine the average cost for blue roof construction and materials. Generally, averages costs for a blue roof range between $5 and $8 per square foot of impervious area treated.[8]

8.8 Applicability to DC Water

With rooftops representing a significant portion of the impervious area in urban settings, application of blue roofs can potentially prove to be beneficial in assisting with CSO's through the delay of the timing of runoff. However, most blue roof installations have confined to public buildings. When compared to green roofs, a blue roof incentive program for the private sector would likely not be successful as they lack the added benefits of green roofs.

8.9 Detailed Design References

Detailed design options are available in published documents and manuals that are periodically updated to keep abreast of advances in technology. Blue roof systems are not as commonly used or referenced as their green counterparts; however, two references were found to be clear and complete and could easily be translated to projects in the Washington, DC region:

- New York City Department of Environmental Protection, Guidelines for the Design and Construction of Stormwater Management Systems - www.nyc.gov/html/dep/html/stormwater/stormwater_management_construction.shtml

- Fairfax County Department of Public Works and Environmental Services, Public Facilities Manual - www.fairfaxcounty.gov/dpwes/publications/pfm/.

It is important to make certain the selected design options are acceptable to the District Department of the Environment (DDOE) prior to implementation and are in accordance with DDOE design guidance. DDOE is currently in the process of revising current guidance and adopting the runoff reduction methodology used by the Virginia Department of Conservation and Recreation (as communicated in an email from Rebecca Stack, DDOE, 3/19/12).

[8] Cost Estimate Sources: DC Department of the Environment Riversmart Program, Water Environment Research Foundation, U.S. EPA, Center for Clean Air Policy, New York City Department of Environmental Protection

8.10 Example Applications

The following provide some typical schematics and photos of blue roof applications:

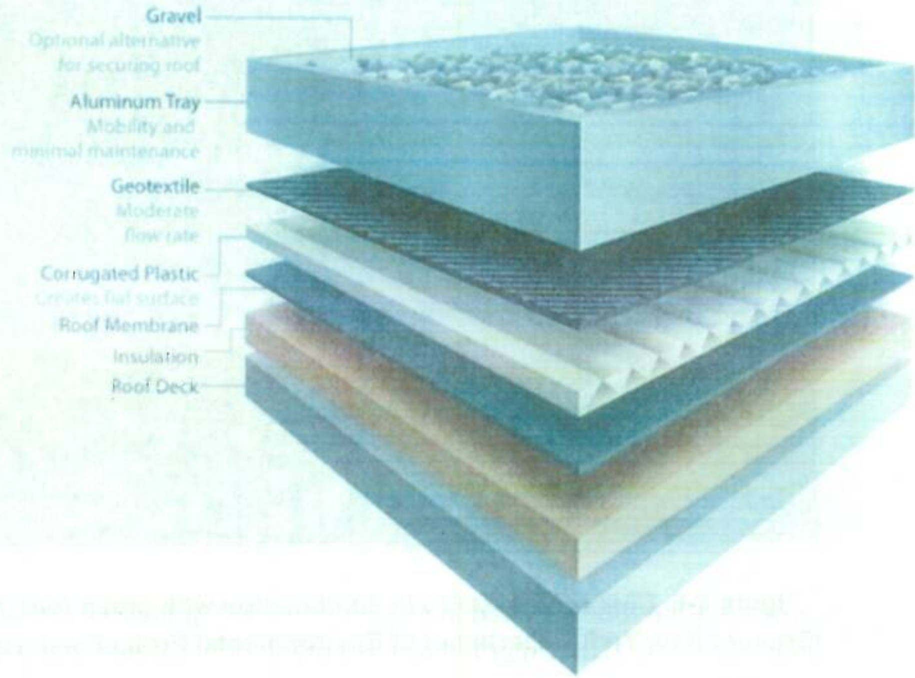

Figure 8-4. Example profile for blue roof system. (Source: Hazen and Sawyer)

Figure 8-5. Typical blue roof modular tray with gravel ballast. (Source: New York Department of Environmental Protection/Hazen and Sawyer)

Figure 8-6. Blue roof installed in combination with green roof, New York, NY. (Source: New York Department of Environmental Protection/Hazen and Sawyer)

Figure 8-7. Installation of a waterproof membrane during blue roof construction. (Source: New York City Department of Environmental Protection)

9 Filter Systems

9.1 Description

Filter systems are structures or excavated areas containing sand, organic matter, or other materials that capture, temporarily store, filter, and treat pollutants such as sediment, nutrients, metals, and hydrocarbons. These systems are useful for treating stormwater on small, highly impervious sites – especially in ultra-urban areas where sufficient space for practices such as bioretention may not available. The filter system often consists of a pre-treatment or settling cell and a filter bed that contains sand or organic material. Filtered stormwater is typically collected in an underdrain and returned to the storm drainage system. Pollutant removal occurs primarily through physical processes, including gravitational settling, straining, filtration, and adsorption in the filter media. Microbial films sometimes form on the top of the filter media, which adds a biological removal component.

There are a wide variety of filter systems and applications. The major categories include sand filters, organic media filters, and proprietary filters. These systems can be designed as surface or subsurface, vegetated or non-vegetated, and with infiltration (no underdrain) or without infiltration (underdrain) – to name a few variations. Filter systems are beneficial in their pollutant removal capability; however, provide little to no runoff reduction. In addition to their applicability in tight, urban areas, filter systems can often be used to provide special treatment at known stormwater hotspots such as parking lots, gas stations, roadways, car washes, fleet storage areas, maintenance facilities, or industrial sites.

Figure 9-1. Surface filter system.
(Source: Portland SWM Manual)

9.1.1 Sand Filters

Sand filters can be designed as either surface or subsurface systems that infiltrate stormwater down through a sand media and filter out pollutants. The effluent is either infiltrated into the ground or collected in an underdrain and discharged. Surface sand filters are typically constructed off-line and only treat the desired water quality volume. However, some surface sand filters are installed in the bottom of dry detention ponds or combined with other BMPs. On-line surface sand filters are often used as perimeter treatment around parking lots or other impervious surfaces. In this case, stormwater flow enters the system through grates at the edge of the perimeter. These perimeter systems are a good treatment option in areas with low topographic relief since little hydraulic head is required.

Figure 9-2. Surface sand filter during construction (Source: Chesapeake Bay Stormwater Network)

Subsurface sand filters work similarly, but are installed underground and are typically more expensive to construct. The trade off with a subsurface system is that they take up very little space and are therefore well suited to ultra-urban areas. Subsurface sand filters are generally designed with a flow splitter that bypasses larger storm events around the filter.

9.1.2 Organic Filters

Organic filters work similarly to surface sand filters; however, the sand is replaced with an organic filtering medium such as peat (typically mixed with sand) or compost. While sand is a good medium for removing total suspended solids, organic filters can achieve higher pollutant removal for metals and hydrocarbons. For example, peat has been shown to remove slightly more total phosphorus, copper, cadmium, and nickel than sand. Care should be taken in placement of an organic filter, as recent research has shown that organic media can leach nitrate and phosphorus back into discharge water, making it a poor choice when the filter is placed near a water body sensitive to nutrient loadings.

9.1.3 Proprietary Filters

There are many proprietary filter devices available that can provide excellent filtering capacity for specific pollutants of concern. For example, Filterra® (manufactured by Americast) uses a sand filter and has been approved by several states as a designated treatment system for suspended solids, oil, and phosphorus; and the Arkal Pressurized Stormwater Filtration System (manufactured by Zeta Technology, Inc.) uses disk filters and has been approved by the U.S. EPA's Environmental Technology Verification (ETV) Program for sediment removal. Many similar products are available in the U.S.

Figure 9-3. Filterra® planters.
(Source: Filterra)

9.2 Feasibility Considerations

Filter systems can be implemented on a wide range of land types and under various conditions. The major limiting factor is typically price, as the practice is not always cost-effective given the area served. However, there are certain situations (i.e., hotspot runoff treatment, ultra-urban areas) where a filter system is the best or only choice. Following are some considerations that should be taken into account when considering a filter system:

9.2.1 Available Hydraulic Head

One of the biggest constraints for filter systems is the available hydraulic head on a site. Depending on the specific project design, it is recommended that 2 to 10 feet of hydraulic head be available since most filter systems require gravity flow through the filter. Therefore, filter systems are difficult to implement on sites with relatively flat topography. As discussed previously, one exception is a perimeter or surface sand filter system which can be installed on sites with minimal available head.

9.2.2 Depth to Water Table and Bedrock

A minimum depth of 2 feet is recommended between the seasonally high water table and/or bedrock and the bottom of the filtering system. Completely enclosed systems are not subject to this constraint, provided the potential impact of inundation is accounted for (buoyancy, discharge configuration, etc.).

9.2.3 Contributing Drainage Area

The maximum contributing drainage area to a filter system is 5 acres; however, one acre or less is preferred. A maximum drainage area of 2 acres is recommended for subsurface or perimeter filter systems. It is also recommended that the surrounding drainage area be as close to 100% impervious as possible. Larger drainage areas and/or drainage areas with higher pervious percentages tend to contribute more sediment and debris which clogs the filter system. On a larger site, multiple filters should be used throughout the site for treatment.

9.2.4 Available Space

Filter systems require very little space, which is one benefit of using them in urban areas or other constrained settings. Sand and organic filters typically use about 2% to 3% of the contributing drainage area. Perimeter systems generally consume less space. Subsurface filters use no surface area except for their manholes or other access points, which can be designed for traffic loadings.

9.2.5 Pollutant Hotspots

Filter systems are one of a few stormwater BMPs recommended to treat runoff from land uses with the potential for high pollutant levels.

9.2.6 In-Situ Soils

The permeability of soils on site may inhibit the use of certain types of filter systems. Many filter systems include an impermeable liner and an underdrain to convey treated runoff. Infiltration filter systems do not employ an underdrain and allow some or all of the treated water to infiltrate into the subsoil. In this situation, permeable soils are required for proper filter system function. If suitable soils are not present on the site they may be amended to provide adequate drainage.

9.2.7 Utility Conflicts

As with other practices, conflicts with utilities (both under and above ground) should be avoided.

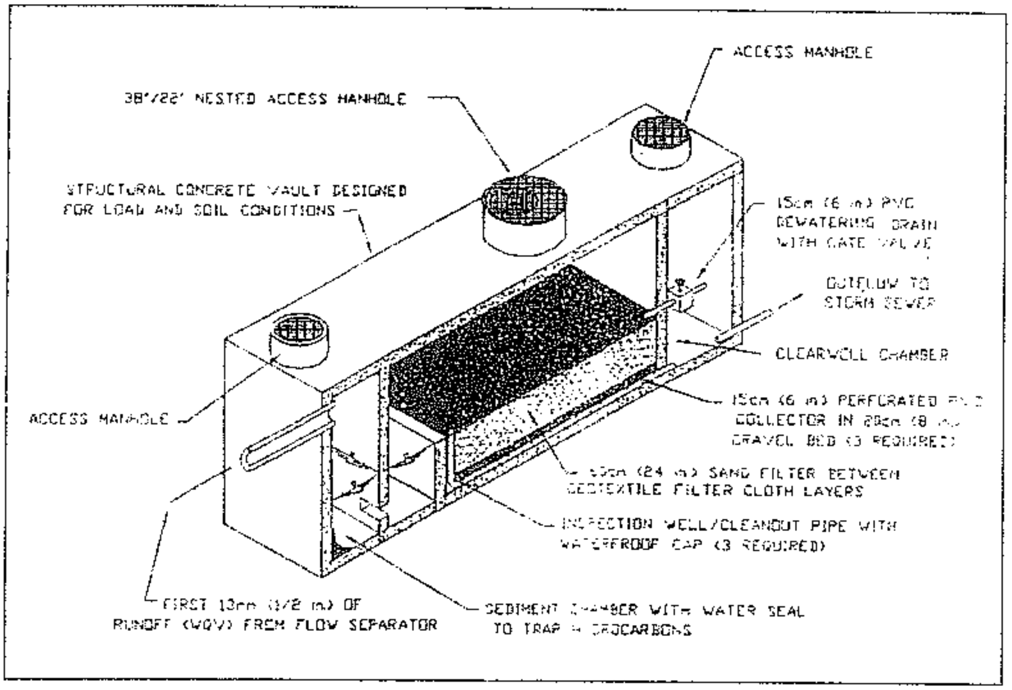

Figure 9-4. Schematic of Washington D.C. underground vault sand filter. (Source: VA DCR SWM Handbook)

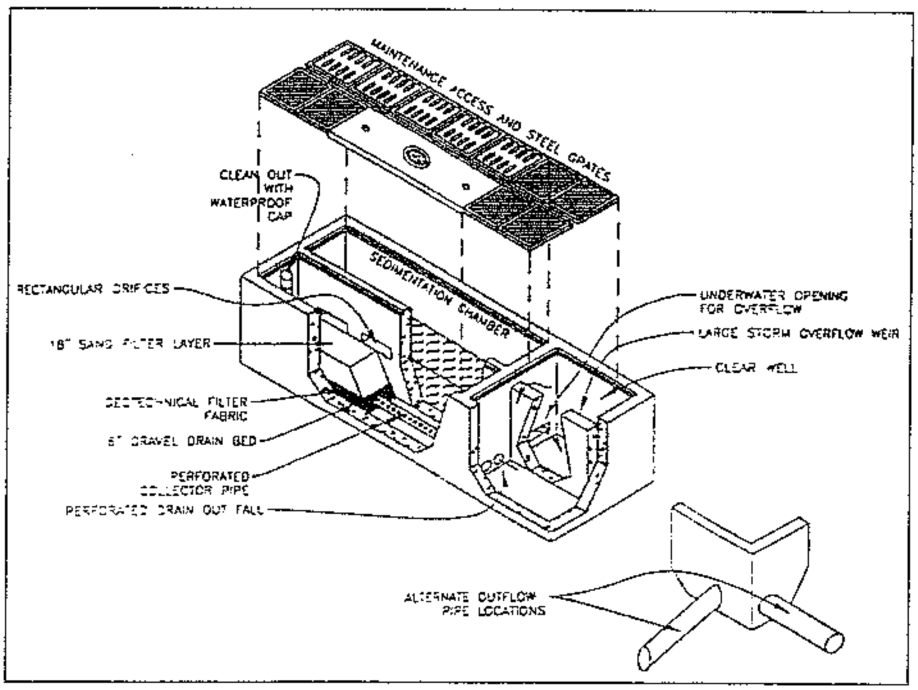

Figure 9-5. Schematic of precast Delaware sand filter. (Source: VA DCR SWM Handbook)

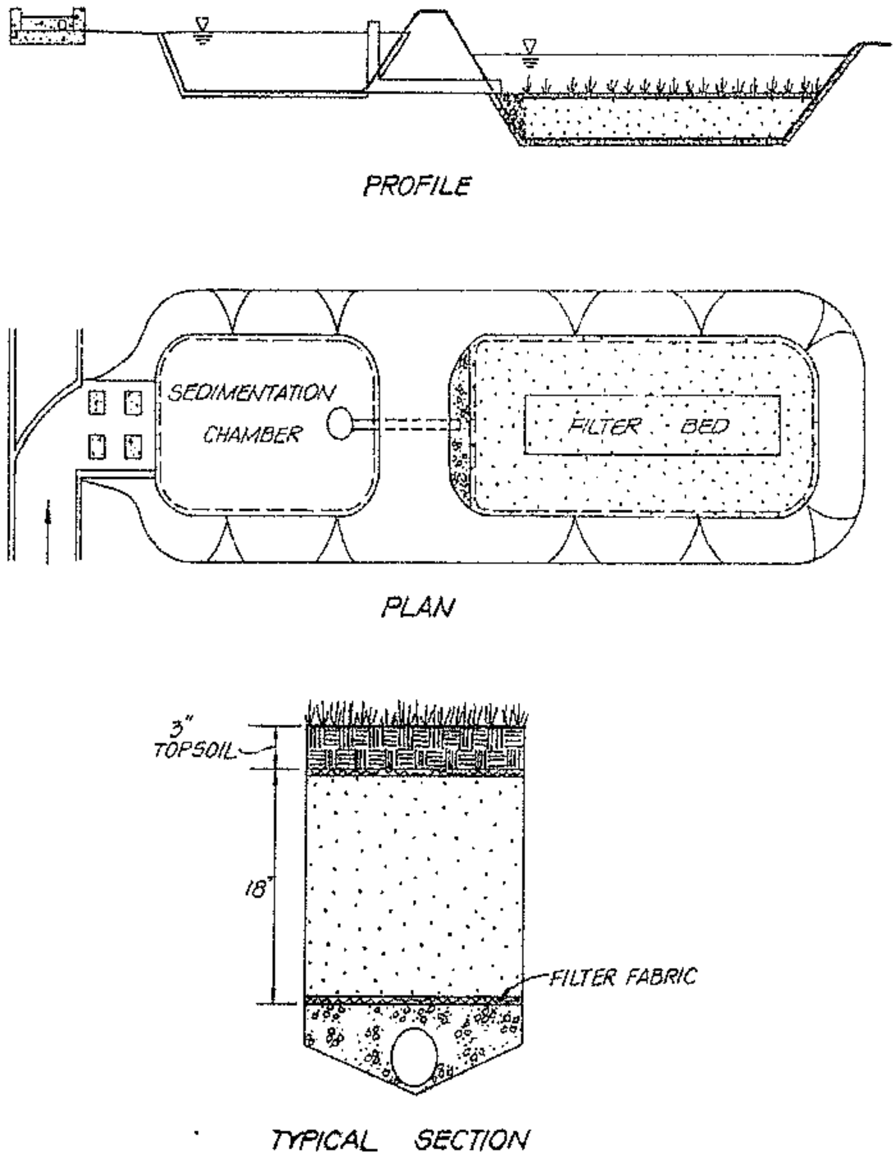

Figure 9-4. Schematic of typical surface sand filter.
(Source: Claytor and Schueler, 1996)

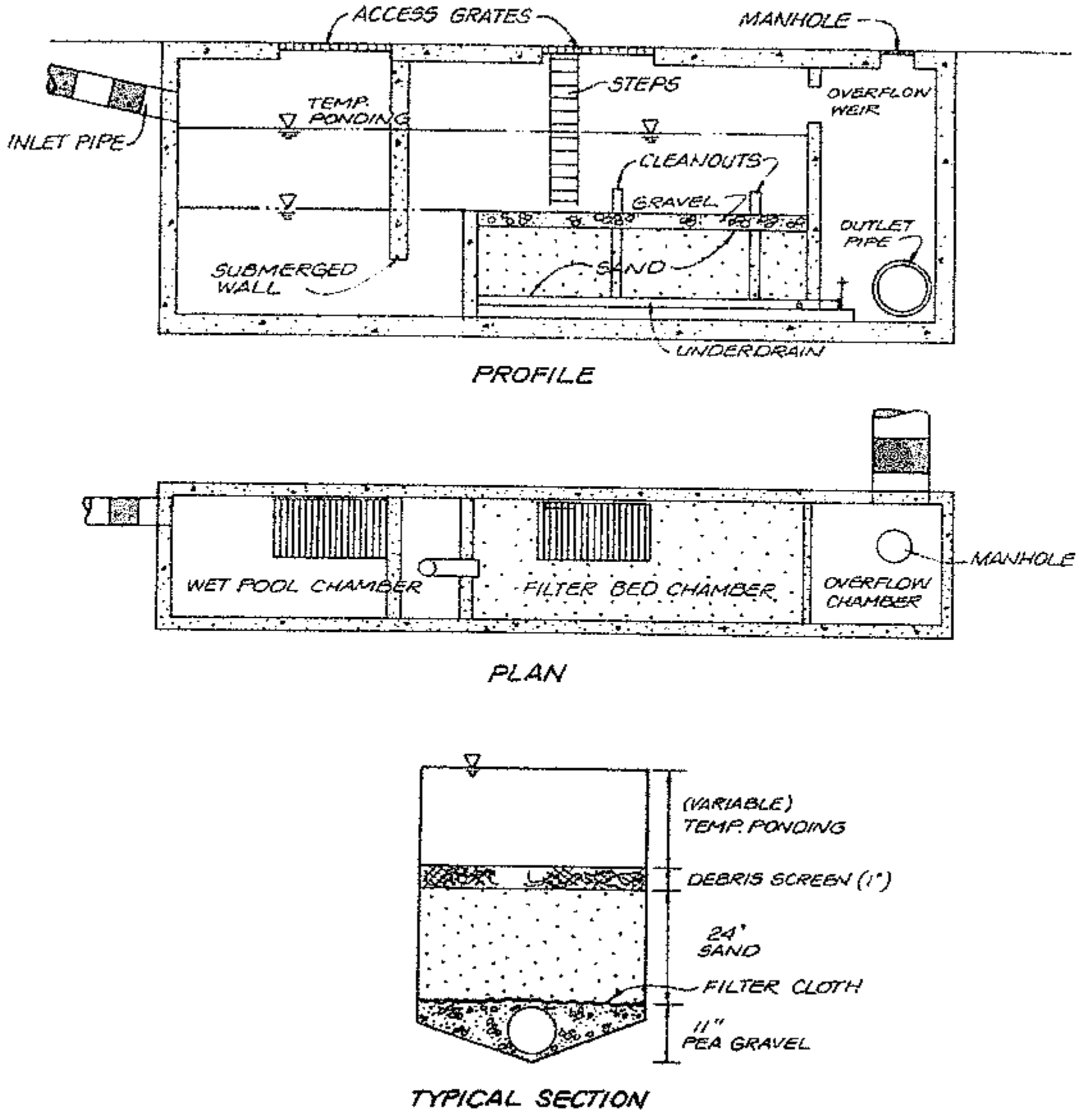

Figure 9-5. Schematic of typical subsurface sand filter. (Source: Claytor and Schueler, 1996)

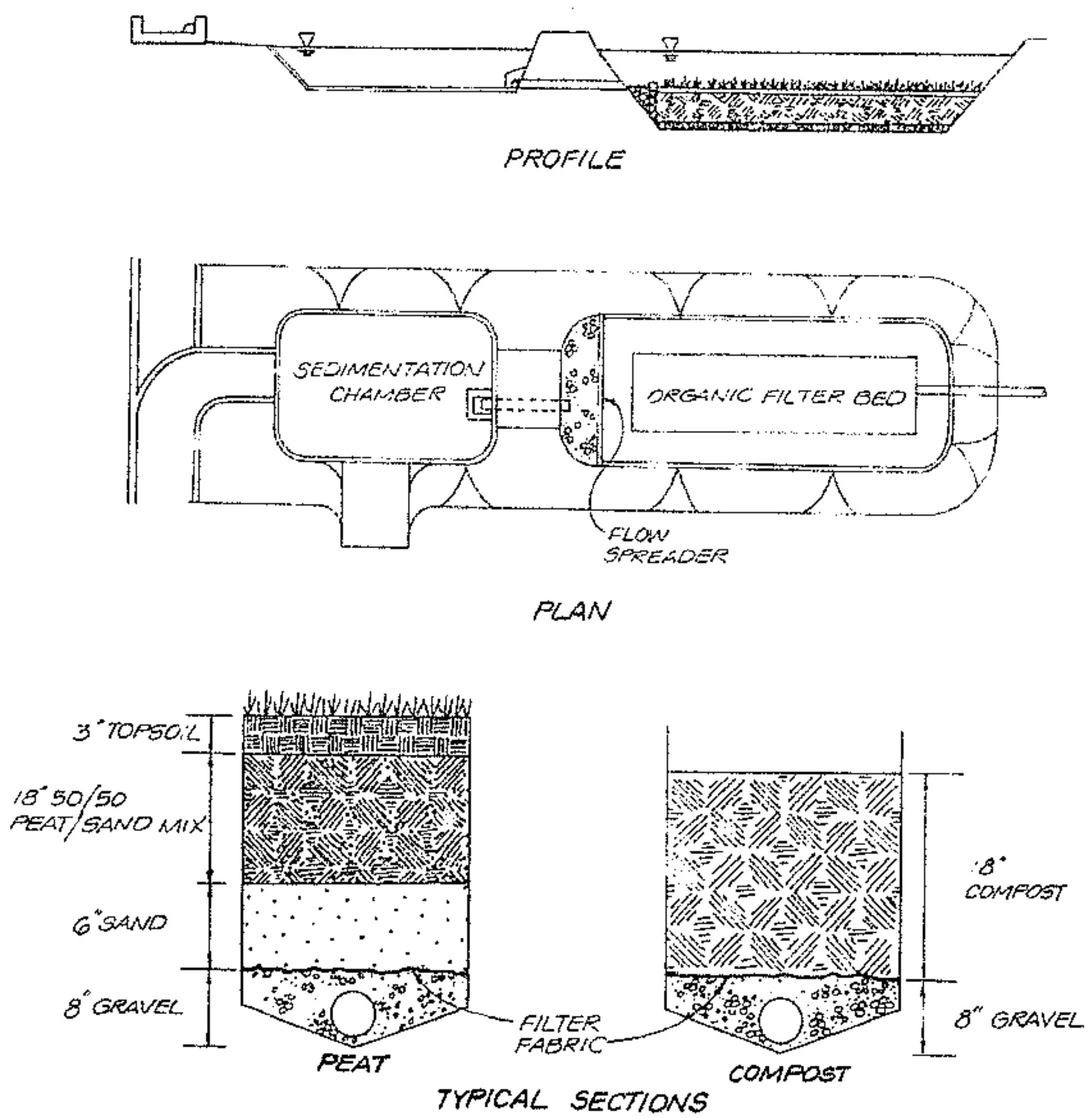

Figure 9-6. Schematic of typical peat/sand organic filter. (Source: Claytor and Schueler, 1996)

Figure 9-7. Perimeter filter system.
(Source: Chesapeake Bay Stormwater Network)

Figure 9-8. Access for maintenance of perimeter filter system.
(Source: LID Manual for Michigan)

Figure 9-9. Sand filter application with vegetation. (Source: Virginia DCR Stormwater Design Manual)

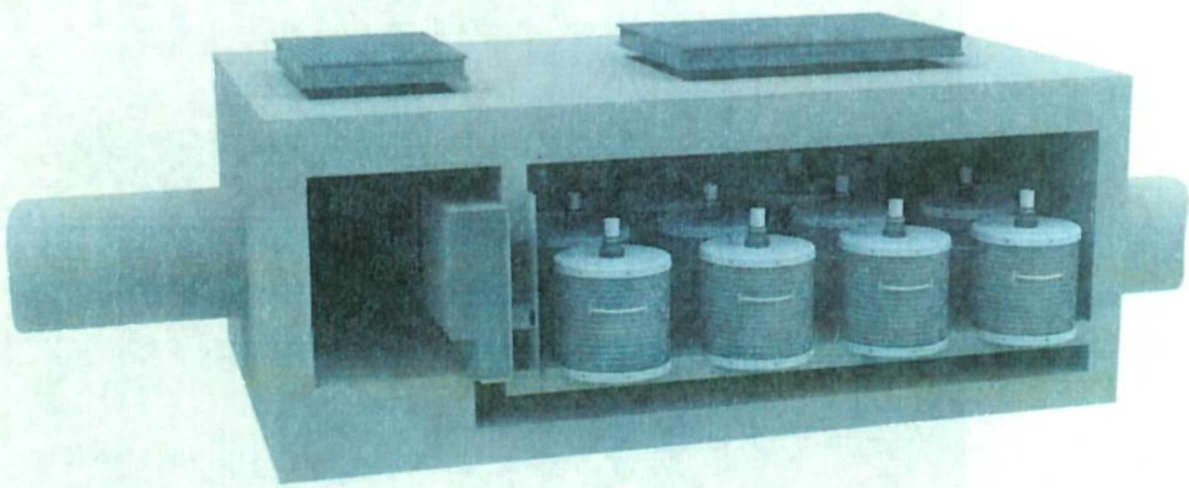

Figure 9-10. Example of proprietary filter system – FlowGard® Perk Filter (vault style). (Source: KriStar)

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Wetland Studies and Solutions, Inc. Gainesville, VA.

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